THE

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THE

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COMPILED TO PROMOTE PRACTICAL EDUCATION.

BY

W. MULLINGER HIGGINS,

LECTURER ON EXPERIMENTAL PHILOSOPHY AT GUY'S HOSPITAL.

Illustrated by above One Hundred Wood Engravings.

"He who does not know that which is of use and necessity for him to know is but an ignorant man whatever he may know beside." —TILLOTSON.

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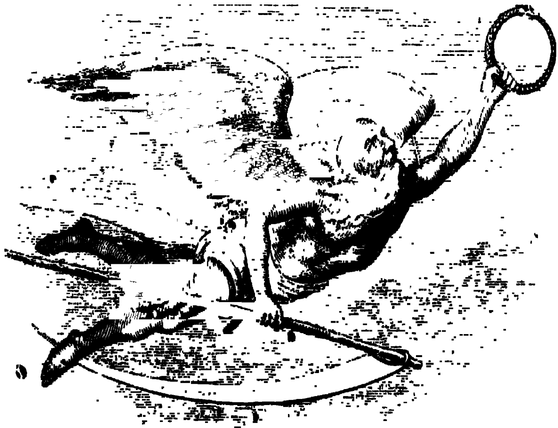


INTRODUCTORY CHAPTER.

MAN, in every period of his existence, and in every state of society, receives his sensations from external phenomena. Inanimate as well as animated objects are constantly presenting appearances which have a mysterious influence on the sentient powers of man. The majority of mankind receive the impressions produced by these phenomena, without inquiring into the agency by which they are regulated; it is the business of the natural philosopher to ascertain the nature and influence of their causes.

Ultimate causes are beyond our powers of analysis; we may approximate to a knowledge of them, but we cannot ascertain their nature, or the actual extent of their influence. Nearly all the appearances in nature may be resolved into the production of motion; and we are capable of ascertaining

its laws, but cannot discover its origin. We may, indeed, resolve all causes into the will of a self-existent, eternal, Being; but there is a link between the will of this Being and the laws of Nature, which our researches fail to supply.

If we examine, on the other hand, the influence of these appearances on ourselves, we are led to the same result. The sun shines, and it occasions in us sensations which are called light and heat. Now the action of a solar ray may be traced from one effect to another, until we have ascertained that it impinges upon a small fibre of the eye, called the optic nerve. By this nerve an effect is carried to the brain, and a sensation is produced; but we can neither determine how the nerve can conduct an impression to the brain, or how the brain can act upon those parts of the human frame which are the seats of sensation.

There are, then, boundaries to our inquiry, not arising from any want of continuity between cause and effect, but from the imperfect nature of our reason. To trace, consecutively, natural causes to the ultimate Being, requires an order of mind higher than that possessed by man. We must satisfy ourselves with a knowledge of the laws which govern appearances, and this is one of the ultimate objects proposed by natural philosophy.

The word *law*, as applied to natural objects, is evidently used in a sense somewhat different from its common acceptation. In reference to inanimate nature, it must be understood as a fixed immutable process of action, the rule by which any appearance is produced.

Now, how are these laws to be determined? Sometimes

they may be discovered by observation. Thus, by narrowly watching the times, circumstances, and conditions, under which a body presents certain phenomena, we may ascertain the causes of those phenomena; and by a knowledge of the causes, we may deduce the law or laws by which that body is governed.

We more commonly endeavour to ascertain the laws of nature by experiments, in which we give activity to causes over which we have a positive control; and, from the results, deduce the laws by which they are governed.

Thus we observe lightning as an atmospheric appearance; but no observations upon it, or upon the attendant phenomena, can give us any certain information of its nature, much less of the laws of that species of matter by which it is produced. We see that it resembles the passage of a luminous fluid from one cloud to another, or to the earth; that the clouds are unusually low; and that it not unfrequently produces devastating effects when it reaches the earth. But these are facts that can never lead us to a knowledge of its cause. We discover, however, or fancy we discover, a great analogy between the appearance of lightning, and the discharge of accumulated electricity,—and it is possible there may be an identity of origin. To prove whether this be, or be not the case, we will endeavour to bring the electricity of the atmosphere—if it be electricity that produces lightning—under our control, and submit it to experiment. We consequently raise into the air a body which will conduct the fluid to any spot that we please, so that it may exert an influence upon those instru-

ments by which the presence of electricity is tested. The results answer our expectations, and it is discovered that electricity is the cause of the phenomenon. But from that knowledge of the electric fluid obtained by other experiments, we are certain that luminous effects are never produced by electricity, unless it is in motion, and then only when it is passing from one medium to another. We have also ascertained that electricity is never put in motion except when the electric equilibrium is destroyed; that is, when one part of a body is in a state different from some other part, or when one body is in a condition opposite to that of some contiguous body. If either of these effects be produced, electricity will be put in motion, and transmitted by any substance that is capable of conducting it.

Having discovered that electricity is present when lightning is seen, we are led to deduce that lightning is occasioned by the spontaneous discharge of the electricity of the clouds.

To the man who has not thus learned to interrogate nature, the universe is a riddle, and the confusion of his ideas is promoted by the deceptions to which he is subject from the erroneous impression on his senses. Not only is he unable to estimate the causes by which phenomena are produced, but he is labouring under the disadvantage of an erroneous perception of the appearances around him. It seems hard to doubt the testimony of our senses, yet they are constantly deceiving us. We do not mean that our senses are habitually deceived, but they are often incapacitated, from the circumstances under which they act, to give accurate information. In attempting to discover the causes of phe

nomena, we discover the errors under which we perceive the phenomena themselves, and are thus able to correct the inaccurate impressions which are conducted to our minds by the senses.

We have already shown how we may ascertain the causes of phenomena, and it is now our business to explain how our senses deceive us in conveying false representations of external appearances.

The organ may be quite capable of conveying with accuracy the impression it receives, but there may be errors connected with external causes, and these it cannot detect. There may, also, be certain conditions, under which it may, from its very construction, be unable to convey an impression, and it may be susceptible of derangements which exert an influence over the character of the sensations it is instrumental in producing. Now, all these causes of error do really exist, and deserve to be examined more at large.

Our organs of sense, excepting the eye, are limited in their conveyance of external phenomena. To the influence of appearances on the eye, there is no natural boundary. Regions, from which imagination has scarcely dared to anticipate an idea, have made their impressions upon it; no body is too distant or too near, too large or too small, to affect it. With the aids which have been offered by science and art, it has investigated almost the ultimate minuteness of bodies, and the largest masses are not too extensive to affect this delicate organ. The eye being the principal medium through which we receive our impression of external objects, it is not surprising that it is most susceptible of deception, and this

fact will explain why the majority of our illustrations are drawn from the visual sensations.

There are few phenomena which are not presented to us under circumstances requiring correction. An appearance is not generally produced by any one agent, but is modified by a series of causes, so that it is sometimes difficult to determine which has most influence in its production. As the senses are inadequate to the detection of causes, so they cannot correct the errors which influence natural phenomena. Of the truth of this statement we might adduce innumerable examples; we will mention a few.

The earth appears, to all who inhabit it, a stationary body in the centre of the universe. Around it the celestial sphere is apparently moving once in twenty-four hours, carrying with it all the heavenly bodies, which seem to be permanently fixed in the deep concavity. An observation continued for a few minutes on the relative positions of the planets proves that they are not permanently fixed. These bodies have a revolution independent of the diurnal rotation, and that motion is found, by further observations, to be confined within a certain zone, called the ecliptic. As soon as we have assured ourselves of this, we begin to have some doubt of the truth of our first impression, that the celestial sphere has a diurnal revolution round the earth. The more extensive our observations, the more permanent are our doubts. We discover that all the stars are not situated at the same distance from the earth, and they do not always appear to have the same motion. Now it is evident we can only conceive of the celestial sphere as in a state of revolution, by supposing

the bodies to be immoveably fixed in it; the relative motion of the planets, therefore, proves that the diurnal revolution is not a real motion, and that we must seek some better explanation.

Only one other cause can be given, and we are compelled to admit that the earth must be the revolving body, however inconsistent the supposition may be with all our former notions. We will now take this admitted fact as an element in our future astronomical calculations, and if we find the phenomena to agree in circumstances and in time with the results of our calculations, we may consider every fulfilled prediction as a proof of the truth of the supposition. Now, this is actually the case; and such is the nature of the evidence by which the diurnal revolution of the earth is demonstrated.

Again, light, in passing through glass, as well as through many other substances, is bent out of a straight course, or, in other words, is refracted. The phenomenon of refraction is one of the most striking instances of the inadequacy of our senses to correct the errors discovered by physical science, and of the consequently erroneous impressions made by them. The atmosphere has, like glass, the power of bending light from its rectilinear direction; and it is a law in optics, that an object is seen in the direction of the visual ray at the moment it enters the eye, whatever its previous course may have been. Now, as the atmosphere intervenes between the eye of every spectator and the heavenly bodies, no celestial object is seen from the earth in its real position. The atmosphere is, in fact, an aërial ocean encircling the

earth; and as air possesses the property of compressibility, the lower portions of the atmosphere must be more dense than the superincumbent. Light has, in its passage to the earth, to pass through a succession of aërial strata, and is bent into a curve, which causes all bodies to appear higher than they really are. For this reason, the sun and the heavenly bodies appear to have risen, when they are actually below the horizon,—and to be above the horizon, when they have really set.

But refraction also distorts objects that are seen under its influence. The sun appears to be round in the zenith and oval in the horizon, the horizontal diameter being greater than the vertical, and the lower limb more flattened than the upper. This distortion of form arises from the rapid increase of refraction as the body approaches the horizon.

The same effects, though not so large in amount, are produced in the passage of light from terrestrial objects, so that we are viewing all things subject to an error of position and form, by which the vision is imposed upon, having no power in itself to correct the errors.

The phenomenon of mirage is intimately connected with that of refraction. It is a spectral representation in the atmosphere, of a terrestrial body; and, although seldom seen, has been a source of superstition in every age of the world. It is well known that in the sixteenth and seventeenth centuries, these phenomena were registered by the prophets of ill, as forewarnings of some direful judgments that were soon to affect a nation, or the human race in general. It is impossible to read the records of the past

without pitying the weakness, or reprobating the deceit, which thus imposed upon the credulity of man. By such means the natural inquisitiveness of the human mind has been repressed, and the wholesome food of thought has been converted into a virulent poison; and in this condition of things consisted the darkness of the middle ages.

Another instance in which we are deceived is in the constitution of light itself, and in the colour of bodies. Our unassisted senses would determine light to be a homogeneous substance, and the colour of bodies an inherent property. We have already stated that light, in passing through glass, as well as many other substances, is bent out of a straight course, or, in other words, is refracted. But, if a ray of light be admitted into a dark room, and be made to fall on the plane surface of a piece of glass in the form of a prism, it is not only bent upwards, but is also divided into rays, having seven distinct colours. Under any other conditions, a spot of white light is formed. By this experiment, therefore, we discover that solar light is composed of rays having seven distinct colours, and that we have been deceived in considering it a homogeneous substance, having but one colour.

When this discovery has been made, we very naturally inquire whether these rays have precisely the same properties, and produce the same effects. From what we know of solar light, we imagine it to be always attended by a considerable development of heat. This heat may be equally divided among the rays of the spectrum, or it may be centered in some one particular ray. For aught that we know

they may all have different properties; and it is equally possible that the removal of one of the rays might so destroy the solar heat, as to cause light to produce the most bitter cold. No real information, however, as to causes, can be acquired by speculation; we must resort to experiment, if we would know the cause of solar heat. Let us place the bail of a thermometer successively in each of the differently coloured rays of the spectrum. By this simple experiment we discover that the temperature is more raised in the red ray than in any other, and in the violet ray least; between these two extremes there is a decreasing elevation from the red to the violet. Light is, therefore, not only compound, but its component rays have different calorific powers. Nor does this at all depend upon the illuminating powers of the rays,—for the yellow is the most brilliant part of the spectrum, and at the extremity of the red the brilliancy is the least. But it is possible that solar light may have rays which are invisible to the naked eye. We know that heat is frequently developed where there is no light, and uncombined heat may attend the progress of the solar rays. An experiment will prove the truth of the supposition. If the bulb of the thermometer be placed a little beyond the red ray, the mercury will rise to a greater height than when in the ray itself. Beyond this point the thermometer is also affected, though the influence gradually diminishes. And hence it appears that the greatest calorific effect of solar light arises from an invisible ray.

It may be said, these are not fair instances of deception. It is true, that nearly all natural phenomena deceive us in

the same way; that is, we are only able to guess of the constitution and properties of bodies, without experiment. But as a variety of opinions, founded on some perceptible property, may be entertained concerning every body, and as only one opinion can be true, it is evident that we may be prompted by our senses to entertain an erroneous opinion of external phenomena. We are, then, in this instance deceived by our sense of sight, since, from its unassisted agency, we could only have imagined light to be a homogeneous substance, having a white colour, and equally connected throughout with a certain amount of caloric.

With such an impression, it is not singular that we should imagine colour to be an inherent property of bodies. But this error must have been removed from the mind, by the remarks which have been already made; for whenever the prismatic spectrum is thrown on a body, the several tints of the spectrum are distinctly shown, without in the slightest degree blending with what may be called its natural colour.

We have hitherto confined our observations to the deceptions affecting the eye in its examinations of nature. Although our other senses cannot be imposed upon so extensively as this, by external phenomena, yet they are all susceptible of erroneous impressions. The sense of taste is, in a great degree, influenced by the condition of the sense of smell; and in numerous ways the sense of touch is imposed upon. The ear, also, is capable of deception, and is frequently deceived by atmospheric or local causes over which we have no control, and the impression of which the organ of hearing cannot correct.

Sound is a sensation produced by the communication of a certain motion excited in ponderable matter by the agency of a conducting body. The kind of sensation resulting from a vibrating body, depends upon the nature of the medium by which the effect is to be conducted to the ear. Some of the gases transmit sound more rapidly than others, and the intensity of the tone produced from the same body will also vary according to the nature of the gas.

It has often been observed, that sounds are much more distinct and powerful during the night than the day, which has been attributed to the repose of the animal creation. Poets have, in all ages, made the remarkable stillness of the hours of rest a subject of song, and have given expression to the solemn feelings of superstition to which the calm universally gives rise :—

> It is the hour when from the boughs
> The nightingale's high note is heard,
> It is the hour when lovers' vows
> Seem sweet in every whispered word.
>
> BYRON.

This remarkable stillness of the night, and the distinctness with which any casual sound may be heard, arises from the equality of the atmospheric temperature. During the day the air is very unequally heated, and there are constant successions of light strata that are rising, and of cold ones that are descending. This inequality of temperature gives rise to an inequality of density, which prevents the easy transfer of the vibrations produced by the sounding

body. But during the night, when the density of the atmosphere is rendered more uniform by the equal distribution of heat, a less interrupted wave is the result, which gives a greater distinctness to the sound.

We might proceed, almost without end, in citing instances of deception arising from the erroneous impressions of natural phenomena conveyed to the mind by the senses. From the few instances which have been mentioned, it is evident that the unassisted senses are frequently incapable of giving us any accurate information concerning the natural phenomena by which we are surrounded, but, on the other hand, they often lead us into error; yet all our sensations—and from these our opinions are deduced—result from the agency of appearances that are without us. Through the impressions thus received, uncorrected by philosophy, the superstitious feelings of our nature are excited and encouraged.

We are not, however, on this account, to disparage the testimony of our senses, though it is necessary we should receive the impressions they convey with care, if not with suspicion. The conditions under which natural causes act, and the manner in which the organs are excited, should be considered, and thus we may be prevented from over-rating the agency of the senses. In the phenomena we have examined, the senses are not the causes of the deception, but the agents by which the deceptions are conveyed to the mind. To correct these errors is one of the objects of natural philosophy, and its capability of doing so is no slight advantage. Thus, in the phenomenon of refraction,

we are deceived because unable to detect the erroneous manner in which the appearance is transmitted to the organ of sight. By experiment we discover, that, in passing through a fluid medium, the rays of light are refracted; and hence we infer that they must suffer the same effect in passing through the atmosphere. The eye might have been fixed for ever on the heavenly bodies, without discovering that their apparent was not their real place; and we should still have imagined the heavens to have had a diurnal revolution round the earth, had we entirely depended on the testimony of our senses.

It must not be supposed that we insinuate, in these remarks, an incapacity in the organs of sense for the purposes which they were intended to perform. Such a sentiment would be in the highest degree derogatory of the exquisite skill displayed in the construction of our animal parts, and their adaptation to the noblest purposes of our nature. The organs of sense are quite adequate to the purposes of man, in the supply of all his physical wants; and if we are susceptible of deception from natural appearances, it is only in those cases where no bodily injury can accrue; and it might even be said, that the very existence of a capability of deception is, when discovered in a single instance, calculated to excite the improveable reason by which man is distinguished. In the formation of animals, it has been an object with the Creator to construct a perfect organization for sensation, suited to the being and habits of the animal. This statement is equally true of man; but at the same time, the Creator has had regard to his intellectual cha-

racter. The human eye is furnished with no organization by which it can correct the phenomenon of refraction. But this error in vision is not in any circumstance detrimental to the physical condition of man, nor would he have been acquainted with the fact, had he not been in possession of reason. That reason led him to an investigation of the earth, and the worlds around him, and that investigation led him to the discovery of the fact. With similar wisdom and benevolence of design, fishes are endowed with some organization by which they can correct the error of refraction, as evidently appears from the facility with which they catch insects that are flying just above the surface of the water.

If there be one statement more distinctly developed in nature than another, it is, that the characteristic sensations of an animal are arranged to suit its constitution and habits. This may be proved by a reference to one or two different classes of animals.

Take, as an instance, the animals belonging to the genus Felis. It is pretty well known that the majority of these animals hunt their prey by night, and that they have an organization of the eye by which they are capable of seeing with a very small amount of light. This has been attributed to the oval form of their eyes; but erroneously, for some of the animals who are able to see, when our organ of vision is unaffected, have a circular pupil, while others have a capability of altering the form of the eye according to the intensity of the light. The lion has circular eyes, but it generally hunts its prey by night. The Angora cat has the

power of changing the form of its eye; when it is exposed to a light of small intensity, it is nearly circular, and becomes more and more elliptical as the light increases, and is almost lineal when exposed to the full rays of the sun. The tiger, also, is capable of changing the form of its eyes from an oval to a circular shape, and that altogether independent of the intensity of light, being chiefly affected by mental impressions. It does not, therefore, appear that the division of the genus Felis into nocturnal and diurnal animals, founded on the shape of their eyes, is at all consistent with the habits of the species, and we must seek some other cause for the explanation of their peculiar facility in seeing with light of very small intensity. For this purpose they have a construction of the eye adapted to collect all the scattered rays of light, however feeble their intensity may be. They are thus able to accumulate the diffused rays, and apply them to the object of sight, when our organ of vision is unaffected.

We find another illustration to our remark, in the construction of the eye of birds. The most evident and remarkable circumstance in the constitution of birds is their facility of motion. Had they been formed, with their great rapidity of flight, without a capability of seeing with distinctness at both small and great distances, the construction adapting them for rapid motion would have been dangerous as well as useless. But they are capable of this, having the power of discerning objects that are at the point of their beak, as well as at a great distance No species of birds possess these varied powers more remarkably than some of the

accipitres, for it is well known that vultures and eagles will descend directly upon a carcass, from heights where, to the human eye, they appear as indistinct clouds.

The eyes of birds are furnished with two peculiarities of construction. In order that they may see objects that are very near, their eyes are furnished with a broad circular rim, which confines the action of the muscles, and thus elongates the axis. That they may see objects that are very distant, the eye is supplied with an additional muscle, called the marsupium, by which they can draw the crystalline lens farther from the cornea. By these two contrivances, which are entirely under the control of the will, they can adapt the eye to any degree of nearness or distance.

It would be interesting to compare the facilities of motion and sight possessed by different birds; and were we to do so, we should find that those which have the greatest velocity of motion have also the greatest acuteness of sight. The accipitres, which rise to the greatest elevations, have also the most perfect vision. These birds, in their lofty flight, exist in an exceedingly rarified atmosphere, and consequently one of small refractive power; and to provide for this, the eye contains a larger quantity of aqueous humour than is possessed by other birds.

In both these instances, the eye, as an organ of sensation, is adapted to the particular habits of the animal; nor is this fact less remarkably developed in the eyes of insects. Generally speaking, the cornea of insects are made up of an infinite number of small, transparent, horny lenses, which

have no external motion. There are, however, some exceptions to this rule. Among them we might mention the eye of the monoculus apus. In some insects we can trace the adaptation of the particular form of the eye to the habits of the animal; in others we cannot, for want of sufficient acquaintance with their constitution and enemies. One of the most remarkable instances of delicacy of construction in this organ, is found in the insect we have just mentioned. The monoculus apus is about the size of a flea, and is common in our ditches, and other standing water. It derived its name from the supposition that it had only one eye; for, on account of the smallness of the head, both the eyes, which are situated in the middle of the forehead, seem to be united. They are composed of a number of smooth bright hemispheres, each of which has a separate motion, produced by the action of a collection of delicate muscles,— a most beautiful arrangement, and contrived, no doubt, for the purpose of enabling it to avoid the enemies by which it is surrounded.

Although the human eye is not provided with so complex an apparatus as many of the lower classes of animals, yet it is impossible to examine it without admiring the skill with which it has been formed, and acknowledging its adaptation to all the purposes contemplated in its construction It is true man has numerous wants, which cannot be supplied by mere examination of nature. A too entire dependence upon his senses will mislead and deceive him, and in cases of perpetual occurrence they require assistance from his invention.

Moreover, it is not a little remarkable, that the human eye is much more subject to disease than the eyes of other animals. But man is in possession of a power by which the majority of these may be removed, and instruments may be supplied to correct the errors which arise from them. Near and long sights are common among us; but, by the use of differently shaped lenses, the inconvenience arising from these diseases may be avoided.

The limits of our vision are naturally small, but we have extended them almost indefinitely, by the invention of the microscope and the telescope. With one we investigate organized structure, so small, that its very existence had been before unknown. With the other we examine the constitution of worlds which appear, without its assistance, only as points in the immensity of space. These are the results of our enquiry; but it must be remarked, that they only tend to the advancement of our improveable reason, and are in no degree connected with the existence of the mere animal life of the human species.

We may now direct our attention to the sources of some errors to which the eye, as an example of the senses, is subject; first of all briefly alluding to two or three circumstances, which would have produced important errors, and have deranged human vision, had not the Creator provided means by which they are corrected.

It is well known, that the image of an object is painted on the retina, and that in an inverted position. But still we see, or think that we see, every thing in an erect attitude. This has been denied by some authors, who imagine that we

perceive all things inverted, and that the sense of touch corrects the error of sight. In proof of this, it is stated, that if a stick with a gilded knob be presented to an infant, it will stretch its hand towards the opposite end. But this is not true; and that objects are perceived in their upright position is evident, from the fact that in all cases where persons born blind have received sight, objects have been seen in their right position, although there has been an indistinctness of vision. This was the case with Cheselden's patient, and in numerous other more recent instances.

It must, then, be admitted, that we perceive objects aright, though the image is inverted when painted on the retina. There is some effect produced between the retina and the brain, by which the error of vision is corrected; and in this circumstance we have a still farther demonstration of the perfect adaptation of the organ to our convenience. But as we have two eyes, and consequently two images are formed—one on the retina of each eye, it may be asked, why do we not perceive all things double? Sir Isaac Newton thought that the single vision was attributable to the union of the optic nerves before they reach the brain; but cases have occurred in which there has been no such union, and yet the objects have been perceived singly. It is now usually explained as the result of mere habit. It may be asked, upon the same principle, why we, having ten fingers, do not receive the impression of ten objects instead of one. When we look upon an object, we are led by experience to direct the eyes upon it in such a position, as to bring its images upon those parts of the retina

where most distinct vision is produced. But, while looking stedfastly on any body, press one of the eyes upwards or downwards, so as to throw the image on some other part of the retina, and a double vision is immediately produced. The influence of habit in causing us to rightly direct our eyes upon an object, is sufficient to account for single vision; but, in addition to this, we might mention the nervous sympathy which probably exists between the two eyes. Dr. Wollaston is of opinion, that a semi-decussation of the nerves takes place upon their quitting the brain, half of the nerve going to each eye; the right half of each retina being formed by one nerve, the left half by the other. By this means a powerful sympathy is established between the nerves, which, independent of habit, would be sufficient to produce single vision. But whether we imagine the effect to be produced by one of these causes, or by both, it is most evident the Creator has provided against the physical disadvantages which must have resulted from a different arrangement.

There is another instance of the same kind, in the insensibility of the punctum cæcum. The spot at which the optic nerve enters the eye, is called the punctum cæcum, and is totally insensible to light, which is supposed to be occasioned by the nerve not being there divided into fibres sufficiently delicate to be acted upon by the luminous rays. There is, therefore a point in every scene of view, to which we are absolutely blind; when the right eye is used, that point is situated about 15° to the right of the object at which we look directly; when the left eye is used, about 15° to the left.

This may be proved by an interesting experiment. Place two black wafers on a white ground, about three inches apart, and, standing at the distance of eleven or twelve inches, look at the right hand wafer with the left eye in such a position, that an imaginary line joining the wafers, shall be exactly parallel to a line which may be supposed to join the eyes. If the right eye be now closed, the left hand wafer will be invisible. The success of this experiment depends upon the image of the wafer falling upon the part of the retina where the optic nerve comes in contact with it.

When we look with both eyes, the spot that is insensible to one eye will be seen by the other; but it will only be half as distinct as if seen with both eyes. Two comparatively dark spots should, therefore, appear in every scene; but this error of vision is beautifully compensated for by a susceptibility, in this insensible base, to be influenced by the light of the retina. It appropriates the light of the retina by absorption, and thus conveys the same impression of colour as the adjoining parts of that nerve. This error of vision is therefore rendered neutral; and the insensibility of the base of the optic nerve would have remained unknown but for the experiment we have just described.

Every one has observed that certain luminous appearances are produced by pressing the eye-ball outward by a force applied between the eye and the nose. A sudden blow upon the eye, or even upon the head, will sometimes be sufficient to produce this phosphorescent appearance. Sir David Brewster has been led, by experiments he has made, to the con-

clusion, that when the retina is compressed in total darkness, it gives out light; when exposed to the light, and compressed, its insensibility to light is increased; and when dilated, it is insensible to all luminous impressions.

But this appearance may be produced by internal as well as external causes. If during a state of indisposition the blood vessels exert a pressure upon the retina, luminous appearances will be produced, to which the fancy of the patient may give a variety of distinct forms. The eye, under all circumstances, when intently fixed upon any confused mass, is apt to imagine that it resembles some shape with which it is acquainted. Every one, probably, has sat by the fire side in a winter's evening, and intently fixing his eye upon the burning coals, has imagined a variety of figures to be represented by the various colourings of the fire. How often, too, have we realized, remembered, or imagined scenes in the passing clouds, or in their reflected images upon the bosom of some peaceful lake. And how much more, then, will this faculty of creating form from confused masses, be exercised by the mind, when under the influence of a deranged organization. To these two causes, perhaps, we may chiefly attribute the phantasms which haunt the couch of the patient, even when he is in the perfect possession of his reason; the production of luminous appearances by the pressure of the blood-vessels on the retina, and the facility with which the eye gives form to any confused mass that may be presented to it. Nor will it now appear strange that the patient is not in any degree relieved from such delusions by closing his eyes.

Another illusion, which must have been frequently noticed by all who have paid any attention to the operation of the organs of sense, is the indistinctness of indirect vision. If we fix the eye steadily upon any object, while the mind is intently engaged, it loses sight by fits of the objects which surround it; that is, all those which are seen indirectly. Fix a round piece of white paper on a coloured ground, and near it place a strip of white paper; then fix the eye steadily upon one, and the other will be lost sight of. The eye is, in fact, only able to see distinctly those objects on which it is directly fixed; but this defect is in some degree compensated for by its extreme sensibility to colour.

This is, no doubt, under certain circumstances, the cause of many of those apparitions which are so often declared to have been seen. In the broad glare of day, when objects are fully illuminated, the slightest motion of the eye will restore any appearance seen obliquely, to its perfect form. But in an apartment where there is only a single gleam of indistinct light, or elsewhere at the time of twilight, a very small amount of light is reflected by bodies; and in consequence of this, indistinct oblique vision is not easily corrected by direct sight.

Another illusion worthy of notice is, the capability of the eye to retain a luminous impression after the object has been withdrawn. According to the experiments of M. D'Arcet, a luminous impression is retained on the retina about the eighth part of a second after the body itself has been removed. The Thaumatrope, or wonder-turner, is constructed on this principle. It consists of a card, with different objects

or parts of an object, on opposite sides; which are so placed, that when a whirling motion is given to it, the parts appear to be united. Thus, a portion of a scene may be painted on each side, and when the card is caused to revolve, the objects painted on the reverse sides will be united, and a continuous landscape will be seen, which results from the duration of the impression upon the retina after the body has been removed.

In connection with this subject, we may mention the phenomenon of ocular spectra, or accidental colours. If the eye has been stedfastly fixed upon a coloured light, and be then moved to a white surface, it will not convey the impression of either the white or the coloured surface, but one differing from both; and that colour, whatever it may be, is called the ocular spectrum. Thus, if we paint an object red upon a white ground, and fix the eye steadily upon it for a few seconds, a bluish-green figure will be seen when the eye is turned upon a white surface; a bluish-green, therefore, is the accidental colour of red. Different colours have different ocular spectra: that of orange is blue; of violet, yellow; and of black, white.

The law of accidental colours is most remarkable. The accidental colour of any ray of the spectrum, is that which is distant from it one half of the spectrum. Thus, if we take half the length of the spectrum, by a pair of compasses, and fix one leg of the compasses in the ray, the other leg will be in the accidental colour.

We are frequently subject to illusions from this phenomenon, of which we are quite unconscious; for, in every

instance in which the eye is intently fixed upon any coloured surface, the accidental colour is produced when it is removed. If the objects be highly illuminated, and the eye be fixed upon them for any length of time, the spectra will be in some degree permanent, and may become dangerous to vision. Sir Isaac Newton's experiments are applicable to this point; but as they are generally known, and are detailed in Sir David Brewster's Natural Magic, it will only be necessary to recal them to the memory of the reader. After examining a reflected image of the sun several times, the spectra became so permanent, that a picture of the sun was apparently painted on every bright object at which he looked. So severely was his vision affected by the experiment, that he found it necessary to shut himself in a dark chamber for three days, before he could recover the use of his eyes: and, when writing to Locke on the subject, many years after, he says, "I am apt to think, if I durst venture my eye, I could still make the phantasm return, by the power of my fancy."

In all the cases we have mentioned, the eye deceives us without being at all influenced by an indisposition of body, though the deception will sometimes be increased by a particular state of ill health. Spectral apparitions, whether occasional or permanent, are chiefly, if not entirely, produced by a morbid state of action in some of the vital functions, which has a direct, though unaccountable, influence upon the imagination. The real cause of this phenomenon is the recalling of images which have been before painted on the retina, by the united action of memory and imagination.

It will hardly be necessary to mention instances of spectral appearances, for but few persons are unacquainted with the works of Hibbert and of Scott. One of the most interesting cases that we remember, is that mentioned by Sir Walter, as having passed under the notice of one of his medical friends. A gentleman standing high in the legal profession, had been many years afflicted by an apparition, which had constantly attended him, and produced a state of irritation that had brought him into a weak and debilitated condition of body. In this stage of the disease Sir Walter's friend was called in for advice, and, after some time, extorted a confession of the source of all the debility and dejection under which the patient was labouring. When the apparition first presented itself to him, it was in the form of a cat, and was not a source of much annoyance; but, after a few months, the cat left him, and a gentleman usher suddenly made his appearance, who, in his court dress, became his constant attendant, bowing him from place to place, and waiting near him in his own apartments. In a few months this phantasm likewise disappeared, and was followed by one of far less amusing character,—by that form which a healthy imagination can hardly paint with steadiness—a skeleton! Conscious of the unreality of the appearance, he endeavoured to divest his imagination of the phantasm; but the gloomy apparition never left him, alone or in company, and he died from the depression of spirit and debilitation of body which it occasioned.

These are a few of the instances in which the eye itself deceives; nor are the other senses, in proportion to the

number of sensations conveyed by them, more worthy of our entire dependence. Do we not, then, live in a vain show? and is it not necessary that some effort should be made, by which we may be able to correct the errors to which we are exposed on every hand? But man is not satisfied with being deceived through and by his sensations, but in every age of the world has sought, so to apply the knowledge he has acquired, as to deceive others.

There can be little doubt that the mysteries of the oracles among the Greeks and Romans were philosophical impostures. At the cave of Trophonius, and the oracle of Delphos, these practices were probably conducted with more skill than at any other places. The man who is unacquainted with the facilities of deception in the hands of the philosopher, can hardly divine the methods by which the wonders of the temple were accomplished. To such an individual, the records of the philosophical historians of the period must be enigmas. It is difficult to imagine that Plutarch, and Herodotus, and Pliny, and Cæsar, and Tacitus, were deceived as to the scenes which transpired in the sacred houses of the Greeks and Romans; and if he admit, for one moment, the veracity of the historians, he will be tempted to account for the appearance presented to the worshipper in the Grecian and Roman temples, as a direct interference of demoniacal influence. Philosophy, when misapplied, is as capable of deceiving mankind, as it is suited to its improvement when directed by a spirit of philanthropy and universal freedom. What a mighty engine is at present in the power of the natural philosopher, were

be willing to use his knowledge for the deception of mankind. As the wave increases in extent as it approaches the shore, so a knowledge of the causes of natural philosophy increases the power of the possessor over the community, in proportion to the shallowness of its intellect. But happily for us, the days of idolatrous and misdirected Christian zeal have passed; and the great aim of those who have acquired a knowledge of nature, is, to inform the ignorant, and improve their species. A general knowledge of nature is no longer confined to the cloister and the palace, but is positively within the power of every man, whatever be his station in society. In the present day it would be almost impossible to deceive the most vulgar audience, for few are so ignorant as to be unacquainted with the methods of imposture that may be practised upon them. Yet it may not be unimportant to briefly notice some of the deceptions to which we are subject by the application of philosophical principles.

The deceptions which might be practised by the philosopher are so numerous, that the relation of them would involve every branch of natural philosophy. We must therefore, confine our attention to the explanation of a few optical experiments, some of which have been used in our own country, with the intention of deceiving, and others are still used for the purpose of amusement.

A concave mirror is one of the most simple instruments of imposture, and has, probably, been used, both in the oracles of the ancients, and in the necromancy of the moderns. The property of a concave mirror is to converge the

rays of light: and, therefore, an object placed before the mirror would be reflected by it to any point that may be required. That the experiment may be presented in its most interesting form, the image should be thrown on a dense body of vapour, and the mirror itself should be carefully concealed. But an image reflected by a concave mirror is always inverted, and it is consequently necessary that the object, whatever it may be, should be inverted, for by this means the image is presented upright.

With a little mechanical contrivance, and by the use of slides similar to those employed in the magic lantern, the priests and necromancers of old might have performed all the experiments which we perform by the magic lantern. We do not know how they managed their mirrors, but there can be no doubt they used them, and for ages held mankind enslaved by the deceptions they employed. Iamblicus informs us, that the ancients were accustomed to represent their gods by casting an image upon smoke, and that the images of living objects were frequently used. The same was done by the magicians of the fifteenth and sixteenth centuries, and the descriptions which are left us of the scenes and of the places, are sufficient to convince us of this.

This method of deception may be very much improved by the use of a correcting lens, of such a convexity, and placed at such a distance, as to enlarge as well as reverse the inverted image.

Reflections from convex surfaces are not less interesting for the purposes to which such contrivances are now applied,

than the concave; but they are less capable of being used as instruments of imposture. By the means of reflection from cylindrical and conical mirrors, we may correct distorted pictures, and produce, from unmeaning figures, forms of elegance and of beauty.

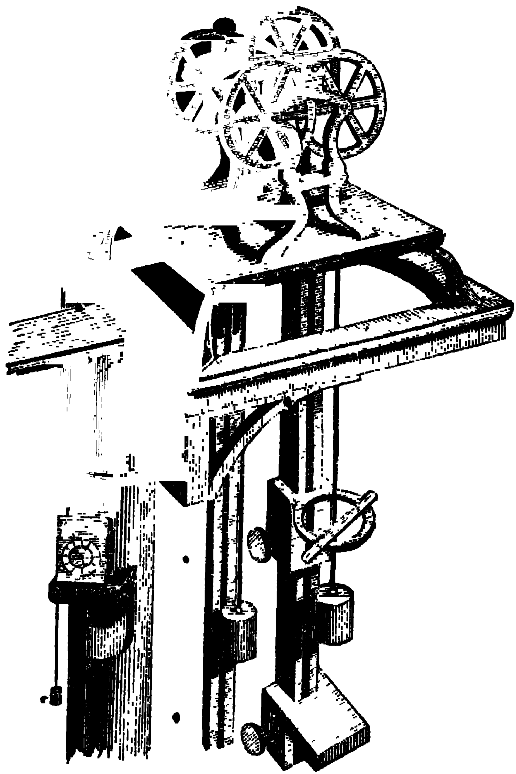
But all these methods of imposture, which may be varied almost in an endless degree, have given way to the use of the magic lantern. This instrument consists of a dark lantern, containing a lamp, and concave metallic mirror as a reflector, to prevent the loss of any of the rays. To this lantern is attached a tube, at the inner end of which is fixed a plano-convex lens, and at the exterior end a smaller convex lens: between these lenses there is an aperture for the admission of a slide, on which is painted the image of the object to be represented.

The light of the lamp, collected by the mirror, is thrown, when the instrument is in action, upon the plano-convex lens, which concentrates it, and thus the slide is illuminated by an intense light. The convex, or outer lens, magnifies the object, and a distinct and enlarged image may be thrown on a wall or transparent screen. But as these images are always inverted, it is necessary to put the slides into the aperture in an inverted position.

The magic lantern has been very much improved by the use of slides which are painted with an opaque colour, except the mere figure; so that the image is thrown on a black ground, and that only is luminous, which makes the deception far more perfect than when it was surrounded by a broad rim of light, as was the case with the transparent

slides. By using these we may throw a figure upon a dense body of smoke; and if the figure be made to move, by sliding glasses, and the lantern be placed in a room adjoining that in which the image is thrown, the deception could scarcely be detected.

It is surely impossible to consider all these sources of deception without feeling the importance of an acquaintance with those principles which enable us to detect the cheat, and in some measure to provide against the errors which would otherwise mislead. Many of the facts mentioned in the previous pages will necessarily come under consideration in other parts of this work, and they have therefore been here as lightly spoken of as was consistent with our object. The argument is calculated to promote inquiry, and if our attempt to illustrate it should lead the reader to an investigation of natural phenomena, he will soon be repaid for the trouble of perusing this essay.



ATTWOOD'S MACHINE.

CHAPTER I.

MECHANICS.

SPACE.

All matter is said to exist in space. Although it is exceeding difficult to define the word space, we may, by a few remarks, obtain a fixed and comprehensive idea. We have all an idea of length; thus when we say that a body is a

foot distant from another body, and that a place is a mile distant in a direct line from another place, we at once perceive, by comparison, their relative positions. We may also have an idea of distances which we are unable to measure. Thus we determine the distance of a star that is situated at the extreme point at which matter acts upon our senses, yet we may imagine another star as far beyond that as it is beyond the spot on which we are observing it. In fact, taking any linear distance as a standard, it may be doubled, trebled, or multiplied to any extent. In the same manner we have a conception of surface, as the superficies of a table or a room, and we may imagine a superficies much larger than any with which we are acquainted. We may also have a notion of volume. The solid contents of a ball, a mountain, or a world may be calculated. But imagine either of these bodies to be hollow, and the interior to be a vacuum, it is evident that it is capable of receiving any substance, though it is absolute vacuity. Now instead of confining the mind to a conception of the volume of a ball or a world," imagine the volume of the universe, or so much of it as is known, and multiply that infinitely, and such is SPACE—indefinite as to our conceptions,—an infinite vacuity, nothing, yet capable of containing all things.

TIME.

The idea of time is entirely dependent on the perception of succession. It is a mental perception of the succession of one thought after another. If we imagine all material objects

to be at rest, the idea of succession, and consequently of time, is still present to the mind; for we are conscious, even when shut out from all exterior objects, that one thought follows another. But if we are removed from this state of individuality, and placed in a situation where we are surrounded by moving material objects, such as the flowing sea, the rising and setting sun, and the planetary bodies, we shall obtain a notion of the division of time; but still the idea of time is not in any degree more distinct, for we only obtain it from a different source: in one instance the idea is gained from a succession of thought; in the other from a succession of material objects.

Strictly speaking, time is indivisible. It is a constant succession; yet, by the perceptible intervals between the occurrence of an event, it may be measured. For the measurement of time there must be some standard, and that standard must be an appearance recurring at constant and equal intervals. The tides, for instance, would furnish us with a standard, did they rise and fall in equal periods. But this is not the case; and there is no phenomenon on the surface of the earth that is presented with a regularity sufficient to warrant its use as a standard of measurement. All the phenomena we observe on the earth's surface are influenced by so many disturbing causes, that their velocity, and periods of recurrence, are continually changing. If we were compelled to select standards from terrestrial appearances, we should find a tolerable, and perhaps the best, approximation, in the periodical changes of vegetables.

Being thus deprived of the hope of finding a standard for

the measurement of time in any terrestrial phenomenon, we must seek for it in the motion of the heavenly bodies. It is a singular fact, that in every age of the world men have been apparently aware of the inexpediency of expecting it in any other sphere of material phenomena. But, although we find the most correct standard by which to measure the lapse of time, in the motions of the heavenly bodies, these do not furnish us with a very obvious method of measurement. The vicissitudes of day and night might give a rude division, and the heliacal rising and setting of peculiar stars—that is, their rising and setting with the sun—at different periods of the year, afford a more extended measure of duration. But the length of the day is constantly changing; and in the course of years, the star that once declared the commencement of a certain period or season, ceases to be its messenger. The ancient Egyptians waited the overflow of the Nile, when Sirius, the dog-star, rose with the sun, but Sirius has for many ages ceased to precede that event; and Aldebaran once rose heliacally on the first of May, but has long since failed to attend the month of hilarity and of flowers.

The motion of the earth on its axis is, however, an event of sufficient regularity to be employed as a standard measurement of time. If we take any other planetary motion, it is equally certain and uniform, but is rendered, by the motion of the earth in its orbit, so apparently irregular, that we cannot, without long calculation, determine its precise change of position. But the time occupied by the earth in a revolution on its axis from west to east never varies; and therefore the apparent motion of the stars from east to west may be

appropriately adopted as a standard by which to compute the lapse of time. The time which intervenes between the period when a star is seen on the meridian, and that in which it returns to the same point, is, by the universal consent of astronomers, called a sidereal day, and has been divided into twenty-four equal parts, called sidereal hours.

The motion of the earth on its axis also gives to the sun an apparent daily motion from east to west; and there are many practical reasons why the sun should be chosen as our standard of measurement, in preference to the stars, although the divisions may not be so accurate. If we observe the sun when on the meridian, that is, at noon, it is seen to descend gradually, and pass over the western horizon to rise in the east, and return again to the meridian. The period occupied in performing this revolution is called a solar day. But a solar day is of longer duration than the sidereal; for although the sun and a star may be on the meridian at the same time to-day, the star will arrive there to-morrow a few moments before the sun. This is occasioned by the apparent yearly motion of the sun in the ecliptic, produced by the real annual motion of the earth. Now when we measure, day after day, the intervals between the successive arrivals of the sun on the meridian, we discover that the period is variable; sometimes it is more than twenty-four sidereal hours and sometimes less. There is, therefore, not only a difference between the sidereal and the solar day, but also a variation in the length of the latter, from which cause we are compelled to take a mean of the whole, and this is called a mean solar day; one twenty-fourth part of which is a mean solar

hour. This division has been adopted as the civil standard of time.

The standard for the larger division of time, a year, has also been selected from the motion of the earth. In consequence of the real revolution of the earth round the sun, as the centre of the system, the sun has an apparent annual revolution in the ecliptic. This motion is not so uniform as that by which the length of the day is determined, and a somewhat artificial arrangement has been adopted to correct the apparent irregularity.

These remarks will, it is hoped, assist the reader in forming an accurate conception of what TIME is, and of the means by which it is measured. The slightest reflection upon the condition of man as a social being, will show the necessity for a division of time, and the benefit conferred on society by astronomy, in providing the means. What would be the state of our large towns and cities, and how could their business be conducted, if there were no means of dividing time by a common standard? It is absolutely necessary for the well-being of society; and this has been acknowledged in every age, and by men of all ranks in civilized states.

Let it be imagined, that these standards of measurement were destroyed, by what means could time be divided, and how could engagements be regulated? We might indeed be compelled to determine its lapse by the dripping of water, or by the burning of a candle; or if we imagine watches and other mechanical contrivances to be known, by what are they to be regulated, and how can their rate of motion be determined? A discordance in our measurements must necessa-

rily result from such a condition; all punctuality would be ultimately destroyed, and a spirit of carelessness and indifference would be introduced into the necessary engagements of life. It is important to the illiterate and the man of letters, to the idler who vegetates in the circle of fashion, and to the man of varied and active employment.

At some past period in the history of man, the accurate division of time may have appeared as absurd to the uneducated portion of the community as many of the expectations of the learned in the present or in recent times do to those who now listen with a vacant and contemptuous stare to the records of scientific improvements. It is true, there must always have been the rude divisions of day and night, which may have been sufficient for the purposes of an almost uneducated people. But as soon as men began to congregate together, to build cities, to surround themselves with their own works, and to shut out the very sight of the great ruler of the day, some better division of time was required; and that astronomy, aided by art, has accomplished.

MATTER.

If we have an idea of space, there will be little difficulty in connecting with it an idea of the existence of matter. We have supposed space to be an idea of infinite extension or volume; but let any portion of space have impenetrability, and such is matter. By impenetrability, is meant the property of occupying any part of space to the exclusion of the

same property. If a substance could be destitute of impenetrability, then any other substance might pass through it without displacing any of its particles. We should not therefore give a very erroneous idea of matter, if we were to say that matter is impenetrability. There are many apparent contradictions to this statement; one of which may be mentioned, as it is likely to strike the mind of the student. It is well known to chemists, that there are some substances, which, when chemically united, have a less volume than the sum of the two. This is the case with alcohol and water. If we take a Florence flask, or long glass tube, and after filling it with water pour off a certain measure of that liquid; and add an equal measure of alcohol, the volume of fluid contained in the vessel will be considerably less than in the first instance. This does not arise from the penetrability of the substances, but is the consequence of the formation of what may be called a new substance, whose molecules approach nearer to each other than the molecules of either of the liquids which compose it. That this explanation is accurate will be the more certain from the fact, that there are other substances which, when united, produce a compound of greater volume than might be expected from their separate bulks.

We are made acquainted with, or become conscious of, the existence of matter through the medium of our senses. By the sight and touch we judge of size and figure; and sometimes we are able to form tolerably accurate notions by the ear. The eye is the most excursive organ; for, by its aid, size and figure may be determined at a distance: but the

touch is often very acute, and particularly so in those individuals who have lost the organ of sight. The sensation of feeling or touch is diffused over the whole of the animal body, but feeling is more acute on the exterior than on the interior surface. The hand is the true organ of touch; and by that only men are generally able to determine, with accuracy, magnitude and figure.

"Matter," says Sir Isaac Newton, "seems to consist of hard, impenetrable, and indivisible atoms. These atoms are supposed to be entirely free of each other; and they are also in themselves indivisible and indestructible, though they may easily be separated from their combinations by chemical processes." But matter is never presented to our examination in its ultimate form, for it is always susceptible of division. It must, however, be at the same time remembered, that the idea of greatness or smallness has nothing to do with our idea of an atom; for we may imagine one as large as a mountain, or one imperceptible to the senses: we may also imagine it to be round, square, or any other shape.

It may be proved, by geometry, that any extension is capable of division; and it is proved with more certainty, by many experiments in chemistry, that matter consists of atoms which are in themselves perfect, and yet incapable of division. Some philosophers have maintained one opinion, some the opposite; but all must admit, that we are greatly ignorant of the ultimate constitution of matter: for although some facts in relation to it may be gathered from the phenomena observed in scientific inquiries, yet the subject is be-

yond the research of the human mind; and it is easier to determine what is not the ultimate condition of matter, than to prove what is.

DIVISIBILITY OF MATTER.

It is exceedingly curious to trace the extreme divisibility of which matter is susceptible in the arts, and the minute forms under which animated being is frequently presented to our view. It may be proved, as already stated, by geometry, that matter is divisible without end; but the recent researches in chemistry make it probable, that all substances are composed of indivisible atoms. It is not our intention to enter upon the abstract inquiry, in which an investigation of the evidence in favour of these opinions would involve us, but simply to bring before the reader a few instances of the extreme divisibility of which matter is susceptible by artificial means, and of the minute forms in which it does exist and possess the principle of life.

The metallic mirrors used in reflecting telescopes, when they come from the hand of the workman, appear perfectly smooth surfaces to the naked eye; but when examined with a strong magnifier, seem to be covered with deep indentations and corresponding projections. Nor is this singular; for when metallic surfaces are polished, their greater eminences only are worn down, and they must still remain comparatively rough; for the powder, whether tripoli, putty, or sand, can do nothing more than scratch the surface in every direction.

If we take a piece of glass tube, and, holding each end, bring the centre into the flame of a spirit-lamp, and raise it to a white heat, we may draw it out to so great a degree of fineness that it shall scarcely be visible to the unassisted eye; yet that fine thread of glass is a tube, and mercury may be made to pass through it.

The oxide of silver is employed to stain glass of a yellow colour. One ounce of silver will stain four hundred square feet; and when the effect has been produced, a chemical means is employed to recover the silver that has not been united with the glass, and the manufacturer succeeds in getting back so much that there is no perceptible loss of weight; from which it will appear, that the divisibility of the matter is such, that four hundred square feet of glass are stained by a quantity of silver which we have no means of weighing.

The extreme divisibility of matter is still more strongly exemplified by the great sensibility of the organ of smelling. If the cork of a vessel containing hydro-sulphuret of ammonia be removed for a few moments, the fetid smell of this substance is immediately conveyed to every individual in a large apartment. If a piece of camphor be subjected to a small increase of temperature, its well-known odour will be soon detected, though the most accurate balance would fail to give evidence of any decrease of weight in the mass. With many other substances the same experiment may be tried with equal success; and in each we have a demonstrative proof of the extreme divisibility of the matter which pervades every portion of the atmosphere, and yet in so minute a con-

dition that no artificial means we possess could detect its presence.

But if we leave the inanimate for the animated being, we shall observe still more striking displays of the minuteness of matter, inasmuch as it is connected with all the capabilities of receiving and of obtaining pleasures suited to its condition. The recent improvements which have been made in the construction of the microscope, and in the application of a powerful light, have opened to examination the conditions and habits of the inhabitants of a new world, whose very minuteness, and the obscurity that has so long overshadowed them, give an interest to our inquiries. Animals, whose existence could not have been discovered without the use of artificial aids, are found to possess an internal organization; and in many instances the ramifications of their air vessels and nervous systems have been traced. As these minute animals have a system for the support of life, they must also be provided with food, which supposes the existence of matter smaller than themselves. In this way we may trace the divisibility of matter, until the mind is tired with the hope of discovering the ultimate minuteness. A description of one or two of the animalculæ will best illustrate the subject.

The larva of a small species of dytiscus, so called because all the animals belonging to the genus are observed to dive, or plunge when approached, is an interesting object for the microscope. Mr. Pritchard has given an account of the animal and its habits, from which we have selected the following facts:—During the spring and summer months, the

eggs from which these larvæ are produced may be found adhering to aquatic plants and confervæ growing near the surface of the water. If a few of these eggs be deposited in a vessel of water, and exposed to the sun, in favourable weather they will be hatched in a few days. When the young first make their appearance, they are of a dark colour, and remarkably active; when a few days old, they shed their skin; and during this operation, which occupies some time, they are almost colourless, especially about the head, all their activity forsakes them, and they abstain from food. The disposition of these carnivorous larvæ is fierce and cruel; they are armed with a pair of bent forceps or mandibles, and with these weapons they seize their prey, and devour it gradually. If the victim be the larva of a gnat or other soft animal, they turn it round, and thus bring a fresh portion within their grasp, alternately opening and closing each mandible till the whole is consumed except the skin. When these animals are unable to obtain other food, they feed upon one another, so that the most fierce and sanguinary contests may frequently be witnessed between them.

The wheel animalculæ, or vorticella rotatoria, to be met with in vegetable infusions, is an exceedingly interesting animal for investigation with a microscope, and is admirably adapted to prove that the smallest development of matter may be endowed with life. It is usually abundant in the stagnant waters of farm-yards, and arrives at perfection in the months of June, July, and August. The largest specimens are about the thirtieth of an inch in length; but those usually met with are not more than half that size, and can

only be discovered by the use of a magnifier. It is most remarkable for the possession of curious rotary organs, by which the animal is able to produce a current towards the opening between its wheels, and thus to bring food to its mouth, which is situated below the neck at the commencement of the body. It feeds on small animalculæ and vegetable matter.

No part of the animal kingdom can more excite our thoughtful admiration than that class which includes the creatures invisible to the unassisted eye. By the aid of the microscope, we not only discover that matter is capable of a divisibility greater than we could have imagined, but that this matter may be in possession of vital powers, and endowed with freedom of motion, a capability of choosing a location, and of selecting food. Nor does our surprise end here; for when we increase the power of our magnifying glasses, we discover that many of these invisible animals are carnivorous, and feed on creatures smaller than themselves, which in their turn possess the same habits. In this way we may trace the divisibility of matter as far as art can aid us, and we then feel we may strive in vain to find any limit of minuteness to the works of the Almighty Creator.

PROPERTIES OF MATTER.

Matter is presented to our notice under different conditions, and according to its circumstances becomes possessed of essentially new properties. Bodies are either solid, liquid

or aeriform; but most substances may be forced to take either of these several states. The most remarkable properties of matter are porosity, compressibility, elasticity, and expansibility: they are possessed by bodies in different proportions.

Porosity.—The molecules or constituent particles of all bodies are separated by the influence they exert upon one another, and the spaces between the particles are called pores. There is reason to believe that no two particles are in actual contact. All bodies are porous, though some in a much greater degree than others. The substances that are most dense—that is, those which have the greatest possible quantity of matter in a given space—are not destitute of this property. Sponge is an example of extreme porosity. Vegetable substances are also extremely porous, as may be easily proved; for if a wooden cup filled with mercury be fitted to the receiver of an air pump, and the receiver be exhausted, the mercury will pass through the interstices or pores of the wood.

The density or specific gravity of bodies is generally decreased as the porosity is increased; for in proportion as their particles are driven away from each other, the weight of any volume of those bodies must diminish. The density of bodies is supposed to be regulated by the forms of their ultimate particles, as the number that may be packed in a given space will evidently depend on their shape. "For example," says Professor Millington, "if it be supposed that a million particles of gold are contained in a cubic inch of that metal, five hundred thousand particles of iron might

also be capable of occupying that same space, or one hundred thousand particles of wood. In the iron and wood there must therefore be more pores or interstices than in the gold, and of course the gold will be the heaviest or most dense. This increased density and weight does not then arise from the individual particles of gold being heavier than those of wood, but from a greater number of them being forced into the same space,—for the original particles of matter are all presumed to be of the same weight; and thus gold, which is one of the heaviest solids, will, when dissolved, remain suspended in ether, which is one of the lightest liquids."

Compressibility.—All bodies which can be diminished in volume, without a diminution of mass, are said to possess the property of compressibility. The compression of bodies is evidently caused by a susceptibility, in the constituent particles, of being brought closer together. This may, it is true, be done by a diminution of temperature; but a body can only be said to possess this property when it can be compressed by mechanical means, and no body can be compressible unless it be porous.

Heat is often given out during compression. A piece of iron as large as the little finger will become red hot when struck a few times with a hammer. After compression has been effected and the iron has cooled, it will not be possible to produce the heat again unless the iron be previously softened. The compressibility of water has been proved by Mr. Perkins; and atmospheric air may be so much reduced in bulk by the use of a common syringe, if properly managed, as to give out sufficient heat to kindle tinder. All

substances are capable of compression, but the degree depends upon the ultimate constitution of the body.

Elasticity is that principle which enables a body to reassume, after a force has been exerted upon it, the form it possessed previous to compression. When air, for instance, is compressed into a smaller volume than its temperature and the pressure of the superincumbent atmosphere would compel it to take, it regains by its elasticity its previous volume as soon as the condensing force is removed; and the power it exerts to do this is in exact proportion to the force with which it is compressed. Atmospheric air possesses elasticity in a remarkable degree. If air had not this property, there would be no force to counteract the effect of the pressure which the lower strata of the atmosphere suffer in bearing the weight of those above them. From these facts it may easily be deduced, that every elastic body is capable of compression, though it is quite possible that a body may be compressible, and not elastic; and under the latter condition it must remain in that shape into which it is forced, or take the permanent impression of the body by which it is acted upon.

We sometimes speak of the elasticity of tension; that is, the force which is exerted by a string or wire in its effort to regain its former length and condition. If it be twisted beyond a certain point, it will take a permanent displacement; but as there are always, when a wire or cord is bent, some atoms which suffer compression and others extension, there must be some attempt to return to the former state.

The elasticity of a body is susceptible of important changes

under particular circumstances. The elasticity of solids is generally decreased by heat; and this is more especially the case with the metals. Gold, silver, platina, and copper, are rendered more elastic by hammering; and the metallic alloys have generally more elasticity than the simple metals. The elasticity of fluids is increased by heat; and it is in consequence of this circumstance that steam has been applied with so much success as a mechanical power. But although we are acquainted with many facts relating to the conditions of elasticity, we cannot determine the origin of this property: it is generally supposed to be the result of a repulsive power diffused around the particles of the elastic body; but this is only an hypothesis, and pretends to no further accuracy than that it will account for the phenomenon.

Expansibility is that property which enables bodies to increase their volumes when acted upon by adequate causes. This property seems to be governed, in some instances, by the diffusion of that unknown principle called heat among the particles of the expanding body. Thus, if we take a bladder containing a small volume of air, and expose it to a fire, or to boiling water, the inclosed air will expand, and fill the whole bladder. But dilatation is, in other instances, produced by the removal of pressure. If we again take a bladder in which a small volume of air is confined, and place it under the receiver of an air pump, the air inclosed in the bladder will begin to expand as that in the receiver is removed, gradually increasing its volume.

The dilatability of the metals by heat, and their contrac-

tion by cooling, has been applied in Paris to restore the walls of the Conservatory of Arts to their perpendicular position, which had been destroyed by the weight of the roof. M. Malard, who superintended the work, placed parallel bars of iron across the building, and passing them through the reclining walls fastened them with nuts: every alternate bar was then heated by lamps, which caused the metal to expand, and the nuts were screwed close to the walls. The bars were then permitted to cool, and the metal consequently contracted; and, being secured by the nuts, drew up the reclining walls. The intermediate bars were then acted upon in the same manner, and the building was at last brought to its perpendicular position.

THE STATES OF MATTER.

Matter in the constitution of bodies may exist in either a solid, a liquid, or an aëriform state. The particular form it assumes will depend on the relative cohesion or repulsion of its constituent particles. If the repulsive force be small in comparison to the cohesive, a solid will be the result: if the cohesive and repulsive forces be so balanced as to give the particles a freedom of motion among each other, a liquid will be produced; but if the repulsive force have the ascendency, then the body will assume the aeriform state. To determine the agent that produces the recession of the particles, and the manner of its activity, are the principal objects in every enquiry into the states of matter.

We sometimes speak of the natural state of a body, but this term is very likely to be misunderstood. There is a condition in which every substance is commonly found, but its particular state may always be considered as the result of circumstances. As water may, under the influence of certain forces, be made to assume the condition of a solid or a vapour, so all other substances, speaking generally, may take either of the three states.

It was supposed by the ancients, and some modern writers have defended the opinion, that fluidity is the consequence of a particular form of ultimate particles, which are imagined to be of a spherical form, hard, and with polished surfaces. The freedom of motion, which they have among each other, induced the supposition, that they were hard with polished surfaces; and the spherical form was chosen, because with this shape they would touch each other in the fewest possible points, while, at the same time, the sphere has the greatest bulk under a given surface; and as friction is according to the surfaces; there would be less resistance from this cause to their motion among each other. If we imagine a number of spheres to be moving upon a plane surface as upon a board or table, there will evidently be a great freedom of motion; but if we imagine one series of spheres to be moving upon another, this cannot be the case, for the upper rows would evidently fall into the cavities of the lower. There is, therefore, a presumption against the spherical form of the ultimate particles of fluids. But, however, this may be, there must be some force to cause the particles to recede from each other, and that cause is HEAT. It

will be our next object to explain the manner in which heat causes fluidity.

Heat is commonly known by its sensible effects, that is, the influence it possesses upon the animal body and the thermometer. Heat may exist in bodies without giving evidence of its presence by any of these sensible effects, and then it is called latent heat, or the caloric of fluidity. It is a common error among those who have not studied the physical sciences, that the thermometer determines the amount of heat contained in a body, but this supposition is not founded on fact, for although it does show the difference of temperature between two bodies, it does not give the relative quantities of heat they contain. The thermometer does that which the sense of feeling may do, though with less accuracy; it determines the degree of sensible heat, but gives no information relative to that which is latent, or in other words, that which is in effect combined with the particles of the body. If we take in one glass a pint of water, and in another five pints from the same spring, they will affect the thermometer equally, though they evidently cannot contain the same quantity of caloric. From this experiment we may deduce, that the thermometer is not a measurer of the quantity of caloric possessed by a body, for it is evident that five pounds must possess more than one. To explain the curious fact, that substances having the same temperature have not, necessarily, the same quantity of caloric, we must suppose that caloric exists, in bodies, in two opposite conditions: in one it is in chemical combination, and, losing its prominent characters, is called latent

heat; in the other it is uncombined or free, and has the capacity of passing from one body to another; and, consequently, produces an effect upon the animal system, or upon the thermometer, and is called sensible heat.

It is latent heat that is the cause of fluidity, whether it be the fluidity of a liquid, or of an aëriform body. An experiment will prove that heat is the real cause of liquidity. Take two connected vessels, and place ice in one, and water in the other; both being at the temperature of 32 degrees. Then put a thermometer in each, and expose them to the heat of a mercurial bath, raised to the temperature of 212 degrees. The thermometer in the water will immediately begin to indicate an increased temperature, and will rise 140 degrees before the thermometer in the ice is at all affected. Both the vessels are exposed to and receive an equal quantity of heat; we can, therefore, account for the difference of effect only, by supposing that the 140 degrees which become sensible in the water is applied for the liquefaction of the ice. It is evident then that a certain quantity of caloric must be received by a solid body, before it can take the liquid state; but the heat that is thus absorbed is not sensible either to the touch, or the thermometer, for the thermometer remains stationary during the whole process of liquefaction.

The statements we have made in relation to the formation of liquids are equally applicable to elastic fluids, that is vapours as a class. If we subject water to the influence of heat, the temperature will continue to increase until it reaches the boiling point, or 212 degrees, and all the heat which is afterwards received will be employed in the forma-

tion of vapour, for how intense soever it may be, the water cannot under common pressure be raised to a higher temperature. It is, therefore, evident we think, that heat is the cause of fluidity; and from many facts we may learn that solids and fluids are but conditions of matter dependent on circumstances.

COHESION.

There is a force called cohesion, or molecular attraction, and by this the particles of all bodies, whether solid, liquid, or vaporous, are held together. Substances are composed, as we have already stated, of portions or particles which do not touch each other. If these particles were not held together by some attractive influence, they would fall asunder, and the world itself would be an unconnected mass.

The cohesive force has not the same intensity in all substances. In iron and some other bodies, it is very strong; but its sphere of attraction is small. On this account they are brittle and hard, not admitting of extension or stretching. In Indian rubber the cohesive force is weak, but the sphere of attraction is large, for it easily suffers expansion without being broken, and returns again to the same place. Between these extremes there are various degrees of cohesive force. Some bodies, lead and Indian rubber are instances, may be made to unite after fracture, and this is usually attributed to their large spheres of attraction.

It is cohesion, then, that is the antagonist force to heat, as it tends to bring together that which heat separates, and

the state of a body must in a greater measure depend upon the intensities of these forces.

REST AND MOTION.

Matter must be in one of two states, at rest or in motion. The idea of rest or motion is simple, and cannot be easily defined, although we may explain our conception of these conditions.

The idea of matter, is, as we have already explained, almost a consequent upon the idea of space, so the idea of rest or motion follows a conception of the existence of separate masses of matter. The idea of situation or place may be a purely mental operation. The mind may, without any reference to organization, have the idea of motion or rest. A blind man, having a conception of space, might imagine himself as a centre, and from that would follow a place higher and a place lower, one to the right, one to the left. When he has proceeded thus far, the idea of relative motion will follow, for he will perceive that a body may remain in the same part of space, or it may be moved from one place to another. There is no absolute motion or rest, for any body in either state, must be so in reference to some other body. If we say, that we are in motion, we mean that we are changing our situation in relation to some objects around us. Two bodies remaining in the same part of space, whatever their distance from each other, are in a state of relative rest. If we imagine one of them to be changing its position in space, then it is in

relative motion, or in other words, in motion relative to the other body. We can have no idea of a body in absolute motion, for to obtain this conception, we must first possess an idea of our non-entity, and the non-existence of all substances, except the one that we are to conceive in motion.

That by which we are surrounded is relative and conditional, and in fact all things are in a condition of relative motion, though not perhaps perceptible to us; and it is true that relative motion and rest may exist at the same moment. Those objects which appear to us most immoveable, the mountain, the ocean, and the lake, are whirling in space, with a velocity ten times greater than a cannon ball, but each is at the same time in a state of relative rest to the others.

Let us suppose a man to be standing in a vessel that is sailing. The man is in relative rest to the vessel, but in relative motion to the shore, because that is the condition of the vessel in which he is placed. But let him be walking to the stern of the vessel, with the same velocity as the vessel is moving a head, and he will then be in relative rest to the shore, in motion as relates to the vessel.

But in whatever state a body may be, it is the result of some cause: there are causes, or, as they are termed by philosophers, forces, which keep a body at rest, or give it motion. To examine the nature and influence of forces is the great object of physics.

This leads us to remark that matter, whether at rest or in motion, is perfectly passive, being entirely governed by forces; and this passiveness is called its inertia. If matter be in mo-

tion its state is the result of some force which is or has been impressed upon it, and it will for ever continue in motion unless some force brings it to rest; and when at rest it will remain in that state unless some force, greater than that which induces rest, set it in motion.

The ancients had a very erroneous idea of inertia. They considered matter to have an attachment to rest, and compared it to an idle man. But it has no propensity for either rest or motion—it is entirely controlled by forces. When a body is set in motion up an inclined plane, it continues to roll upwards as long as the force which propelled it is greater than the force of gravity which tends to bring it downwards Now the matter itself is inert and passive. It is the same with our earth; in some parts of her orbit she revolves with a much greater velocity than in other parts. but this increase of velocity is not fortuitous, for, by a knowledge of the forces which are acting upon it, we are able to calculate the increase or decrease of motion in any part of its periodical journey.

A body is at rest when in equilibrium: if a body be suspended from any fixed point by a thread that is able to sustain its weight, it will be in equilibrium. It is acted upon by two forces, one which is represented by the tension of the thread, and the other, the force of gravitation; and they, acting in opposite directions, keep the body at rest.

Another condition of equilibrium is where the forces are destroyed by some resistance. The largest and heaviest fishes can at pleasure keep themselves at rest in any part of

the body of water in which they float, resisting the forces that act upon them. Every substance on the surface of the earth, or above it, is attracted towards the centre by a force called GRAVITATION, of which we shall presently speak; but its influence is prevented by resistance, and relative rest is maintained. This condition of equilibrium is, however, only a modification of that already spoken of, for the resistance is in fact a force.

Sir Isaac Newton in his principia has given the whole doctrine of inertia upon which the circumstances of motion or rest mainly depend, in the three following propositions:—

1. Every body must persevere in its state of rest, or of uniform motion in a straight line, unless it be compelled to change that state by forces impressed upon it. Motion is as naturally permanent as rest, and a body in motion would continue in motion for ever, if nothing disturbed its progress. The two causes which tend, in an especial degree, to destroy motion are friction and the resistance of air. How greatly friction retards motion is seen in the objects which are daily presented to our notice. It is far more difficult for horses to draw a carriage over a rough than over a smooth road, because a greater friction is produced. For the same reason, a ball will roll a much shorter time on a carpet than on a sheet of ice.

Two windmill vanes, one having its edge in the direction of its motion, and the other opposed to it, stop at very different times, although the same force may be communicated to each. But if they are placed under the receiver of an air pump, and the air be exhausted, they will go for a

much longer time, and will stop together, for the resisting force is removed.

2. Every change of motion must be proportional to the force which is impressed upon the moving body, and must be in the direction of that straight line in which the force is impressed.

3. Action must always be equal and contrary to reaction; or the actions of two bodies upon each other must be equal, and directed towards contrary sides.

These principles being remembered, the reader, however unacquainted with mechanical science, will have no difficulty in following us through our future enquiries.

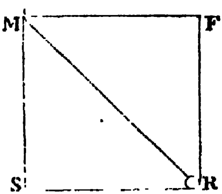
RECTILINEAR MOTION.

When a body receives the impulse of an instantaneous force it moves, by virtue of its inertia; and it moves in a rectilinear direction, governed altogether by the force which has been impressed upon it. It must then obey the first law of motion, and continue to move in the same straight line for ever, unless some other force interfere, and by its superior power compel a state of rest. There are many reasons why bodies moving on surfaces are neither constant in their motion, nor always rectilinear. They are opposed by the force of gravity attracting them to the centre of the earth, by irregularities which are turning them from their direction, and by the deadening influence of friction.

But let us suppose a body having traversed a certain space to experience a new impulse in a different direction. It is

evident that its motion will change both as to direction and velocity, and the amount of change may be determined by knowing the direction and intensity of the force.

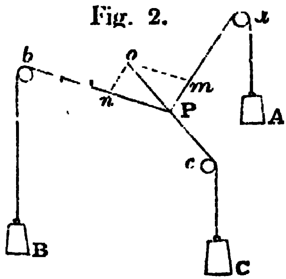
Fig. 1.



Let R (fig. 1.) be a body exposed to two forces, one in the direction RF and the other in the direction RS; and each of the forces shall be represented by the lines FR and SR. It is certain that no two or more forces can impart more than one motion, and therefore when several forces are acting in different directions upon a body, its path must be determined by the direction and intensity of the combined forces. That motion then which results from the action of a number of forces is called the resultant. Let us complete the figure we have commenced, and draw FM equal and parallel to RS, and SM equal and parallel to RF; the diagonal line RM will represent the direction and intensity of the force which gives motion to the ball R.

We may further illustrate the manner in which we find the resultant of two or more forces, or in other words find the direction and intensity of some one force, that will balance the effects of two or more forces.

Fig. 2.



Let P (fig. 2,) be a point to which three strings are attached, and let each string pass over a grooved wheel. To the strings Pa and Pb attach weights; and the point P will be drawn by two forces A and B in the directions

Pa, Pb. Now what is the resultant of these two forces, or in other words, what single force would have the same effect upon the point? Let A be equal to three ounces, and B equal to five ounces. Then take a length Pm on Pa equal to the number of ounces in A, for instance take three inches for three half inches, and on Pb draw Pn equal to five parts from the scale. Now let these two lines be parts of a parallelogram: complete the figure, and draw the diagonal Po. A weight acting in the direction Po, and having the same ratio to it as A and B, have to the lines Pm, Pn, will be the resultant, that is, the force which will be equal to the two forces A and B.

To prove this, place a wheel, c, in such a position that when a string attached to B is stretched over it, it may be a continuation of the diagonal. Suspend from this line a weight having the same proportion to A and B as Po has to Pm and Pn. Now let the point P, which we have hitherto supposed to be fixed, be set free, and it will remain at rest, showing that the weight c neutralizes the influence of the two forces A and B.

These demonstrations will make it unnecessary for us to explain the manner in which we may compound a force; that is, determine the direction and intensity of any two or more forces, that will produce the same effect as any one force.

It would not be difficult to select many examples of the composition of motion. There are indeed but few instances in which we can trace the existence of motion to a single force, and if the reader will take the trouble to reflect upon

the phenomena he sees, he will find no difficulty in selecting illustrations—we will mention one.

When a boatman wishes to cross a river which has a rapid current, he does not row with the head of the vessel towards the point where he wishes to land. If the wind and current were in the same direction he would do so, for the straight line joining the two places is the shortest. But under the circumstances we have mentioned, the boatman must make for a point above or below that which is his destination, according as the current may be moving upwards or downwards. As there are two forces acting upon the boat, we may represent them, according to their momentum and direction, by right lines; and if these lines be considered as parts of a parallelogram the boat should take the direction of the diagonal.

MOMENTUM.

The quantity of force possessed by a moving body is called its momentum. The momentum is governed by two circumstances,—the weight of the substance, and the velocity with which it moves. To find the momentum of a body, multiply the weight by the velocity. Let us suppose one body to weigh twenty pounds, and to move with a velocity of three miles in a minute; and let another weigh ten pounds, and move with a velocity of six miles in a minute. If we multiply the weight and velocity of these together, we shall find that they have both the same momentum which is equal to sixty, and the same force will be necessary to stop them.

FORCE OF GRAVITY.

We come now to consider a force which has an universal influence upon matter, and that is the force of gravity, or as it is sometimes called gravitation. Every particle of matter has an attractive influence upon every other particle, and it is on this account that bodies, when left to themselves, and raised to an elevation above the surface of the earth, fall downwards until they meet with some surface capable of supporting them. This phenomenon is witnessed as far above and beneath the surface of the earth, as human ingenuity enables man to perform his experiments. It is this which causes the rain and hail to descend, and water to seek its level. If this force had no existence, a body once projected from the surface could never return to it, but would float in that portion of the atmosphere in which the resisting medium destroyed its momentum; or if it passed the limit of resistance, would continue in rectilinear motion through space. But it is evident that gravitation is universal: the matter of the earth has such an influence upon all projected bodies, that their line of direction is perpendicular to its surface; not the surface as it is with all its mountains and inequalities, but as it would be if the ocean were carried over it.

Let us, for the sake of illustrating the force of gravity, suppose it to be confined to the earth. The terrestrial attraction does not, it may be supposed, exert the same influence upon all bodies; and in proof of this opinion it will

perhaps be stated, that a stone or any other dense body falls with greater rapidity than a cork or a feather. This, however, does not affect our assertion, for the light body falls more slowly than the heavy, only because it presents a greater surface, in relation to its weight, than the heavy body, to the resistance of the air. If any two bodies, a feather and a piece of metal for instance, be made to fall through a vacuum from any height, they will reach the base in the same period, which fact evidently proves the statement.

The force of gravitation is such, that every particle of matter attracts every other particle. The gravity of a body must therefore depend upon the quantity of matter it contains. Let us suppose a body to contain half the quantity of matter possessed by our earth, and let the two bodies be brought within the sphere of attraction. The consequence would be that each would attract the other; and if we suppose the earth to approach towards this imaginary body at a rate of one mile in the first moment, the other body would approach towards the earth at a rate of two miles in the same period.

Another important law of gravitation is this:—the force decreases as the square of the distance increases, or in other words, it decreases as the distance multiplied by itself increases. If a body attracts some other body with a certain force at the distance of one mile, it will attract it with one-fourth that force when at the distance of two miles; with one-ninth that force at the distance of three miles; and so on: this is called the law of diminution.

If the line of direction of falling bodies be perpendicular to the surface of the earth, and if the earth be a spherical body, no two substances falling downwards, nor any two bodies suspended by lines, can be, strictly speaking, parallel to each other. And yet if we take two plumb lines and suspend them from points a few feet apart, they will appear to be perfectly parallel. But this is easily explained;—the distance between two observable bodies is so small in proportion to the radius of the earth, that the bodies must appear to fall in perpendicular lines. If we suppose two bodies to fall upon a sheet of water twelve hundred feet distant from each other, the inclination of their lines of direction would be only a two hundred and fortieth part of a degree. It is not then singular that two suspended substances sufficiently near to be compared should be, apparently, perfectly parallel.

By a knowledge of the fact that bodies attract each other in proportion to their masses, we may account for the phenomenon that all substances projected into the atmosphere fall towards the earth, and not the earth towards them. If a body as large as a mountain could be raised to the very highest stratum of the atmosphere, and from that situation be left unsupported, it would fall to the earth, and the earth would scarcely move; there is so great a want of proportion between the masses of the two bodies.

Gravitation is an example of what is called a centripetal or centre seeking force, and the various attractions exhibited by bodies under different circumstances, with but one exception, are of the same nature. The general laws of centripetal action have been already stated: that the mutual attraction

of two bodies increases in the same proportion as their masses are increased, and as the square of their distance is decreased; and decreases as their masses decrease, and as the square of their distance increases. These laws have been established by mathematical demonstrations, founded on accurate experiments made in various ways: and by their application in astronomy, a variety of far more complicated problems have been determined. They may, indeed, be considered as the foundation of all accurate astronomical calculations.

By the centripetal action of the sun upon the planets they are restrained within their proper boundaries, and revolve in the same curves for ages together, without any sensible variation. This force keeps up the continued motion which was first impressed upon those revolving bodies by the Creator and it equally governs those immense masses, and their smallest particles. The drop of rain forms itself into a globular shape from the centripetal action of its particles and then falls to the earth, because of the centripetal force of that body

CURVILINEAR MOTION.

Sir Isaac Newton has illustrated his doctrine of curvilinear motion by considering the state of a stone, whirled round in a sling. We observe in this experiment that the stone makes an incessant effort to fly out of the sling, but is restrained as long as the string of the sling is held in the hand. Now the string represents the centripetal force, the stone the revolving body. The endeavour which it makes

to leave the string is called the centrifugal force, and it is evident that the composition of the centripetal and centrifugal forces exerted uniformly for any length of time, produces the rotation of the body round the hand which detains it. We must, however, perceive that something is necessary in the first instance to develop the centrifugal force. The string may be attached to the sling, and the sling may be supported, but it is necessary that some impulse should be given before the sling will, revolve. The hand commences the operation by a sudden effort, and that effort is called the projectile force.

The centrifugal force depends conjointly upon the velocity of the body, and the curvature of its path. If any body move in a curve it will, as we may see in the case of the sling, fly off in a straight line as soon as the centripetal force is taken away.

The primary cause of planetary motion was a projectile force impressed on the bodies by the Creator. The motion is perpetuated by the attraction, which restrains them in their orbits, and neutralizes the centrifugal force. We have already stated that a body acted upon by two forces, in different directions, has a motion compounded of both. In the same manner a curvilinear motion is produced by the united action of a centripetal and projectile force. Curves themselves, as geometricians have shewn, may be considered as nothing more than an assemblage of minute straight lines of small magnitude, and arranged after each other according to a law which varies in each curve.

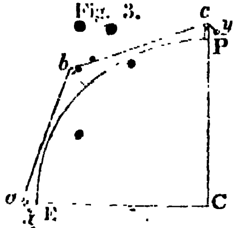
It has been proved by astronomers that the earth has a

revolution on its axis. This rotation causes the matter of which the earth is composed to revolve in circles round the different parts of the axis. But the distance of the surface from the axis varies, and the centrifugal force of any revolving body is in proportion to its distance from the centre. Hence it would follow that the centrifugal force of our earth is greatest at the equator.

The result of this has been the swelling out of the equatorial regions. This effect may be observed by giving a flexible hoop a rotatory motion. It is also found that the ellipticity of the equatorial regions of other bodies is in proportion to the velocity with which they revolve on their axes. Thus Jupiter and Saturn, which revolve more rapidly than the earth, have a greater ellipticity.

Let us now see how the centripetal force acts in relation to the earth. If the central force were not sufficiently strong to neutralize the effect of the centrifugal, the detached bodies on its surface would be thrown off into space. But even under present circumstances it has the effect of diminishing the weight of bodies at the equator, that is, decreases their pressure upon resisting substances. If the earth did not revolve on its axis, the weight of bodies would be the same at all places equally distant from the centre.

Fig. 3.



Experiments have proved that the difference between the weight of the same body at the equator, and at the poles, is one in one hundred and ninety-four. Let EC (fig. 3) be the equator, and P the pole of the earth, and imagine it

possible to have a series of pullies *a b c*, extending from the equator to the poles, and over these let strings be extended with equal weights *y* and *x* attached to each end. If these two weights exactly counterpoised each other, at any part of the earth's surface, that is, were precisely the same, the one over the pole would be one part in 194 greater than that at the equator, supposing the string to have no weight.

It may not, however, be readily suggested to the reader, by what means we can measure the difference of weights in any body at different places. When we weigh any substance we only counterpoise it with some other substance of known value, and if an alteration of weight be produced upon one, it will be to an equal amount upon the other.

The vibrations of the pendulum offer a ready means of determining the alteration of weight. It is found that if a pendulum be made to vibrate at different places, and if the number of oscillations in any period of time be counted, the intensities will be as the squares of the number of vibrations. This, however, is not to be entirely attributed to the centrifugal force;—it arises in part from the elliptical figure of the earth.

The observations of a celebrated French philosopher, on weight, may be appropriately introduced in this place. It is important, he says, in civil and commercial relations that the set weights which are used should always be the same, or at least that they should every where have a known and invariable relation to some determined weight as unity. It is also important to science, that the unit of weight should not be lost: we should be provided with a means by which we

may at all times verify it with exactness, and compare the results of one period with those of another.

The unity of weight which has been lately adopted in France is the *gramme*, which is the weight of a centimeter cube of distilled water, taken at the maximum of condensation. If the length of the centimeter should be lost, it may be easily re-found, since it is the hundredth part of a meter if the metre itself should be lost, it may be found again, for it is the 10,000,000 part of the arc of the meridian of Paris. Lastly, if the earth itself should change its form and magnitude, the metre would be lost, but at the same time every thing would be changed with regard to us; days and nights could no longer be the same periods, nor the seasons the same in course and duration. Every thing in our most fundamental principles is conditional, and science has done its best when it has established its basis on the stability of the world.

Another example of curvilinear motion is to be found in the path of projectiles. The celebrated Galileo, to whose discoveries we shall have frequent occasion to refer, proved that if any body be projected from the surface of the earth it will proceed upwards, and descend again in a parabolic path. Galileo found that a bomb, in its flight, would not proceed in a rectilinear course; but that, by the attraction of the earth, it would be gradually bent into that curve called the parabola, describing one half of that curve in its ascent,

and the other half in its descent. His pupil, Torricelli, extended this observation to some other cases.

But when artillerymen put this theory into practice, they found so many unaccountable exceptions to it, that not only in firing bombs, but also heavy shot, it led them into the most erroneous results. A ball fired out of a field-piece with half its weight of powder, and which according to this theory ought to have been carried six miles, did not reach quite so far as half that distance.

Those who have stood at the breech of a piece of ordnance, and observed the path of the shot when fired at sea, will be aware of one circumstance which Galileo did not take into account The shot, when discharged, ricochets along the surface of the water; that is, alternately strikes the water and rises into the air at the distance of every few hundred yards. For instance, if it be fired from a short cannonade, it will, upon parting from the piece, rise instantly into the air; then descending splash the water in every direction and mount up again. The whistling sound produced during its passage, arises from the resistance of the air; and the variation in the path itself is produced by the same cause.

As the makers of cannon shot are not careful to have them exactly spheroidal, the inequalities of their surface is another cause of error. The surface of the small shot used by sportsmen are, on the other hand, without irregularity. The manner in which this advantage is secured is highly ingenious. It is said that a Mr. Watt, a native of Bristol and a plumber by trade, had a dream in which he saw the

whole contrivance. A person appeared before him on the top of a high tower with a sieve in one hand, and a ladle of melted lead in the other: the lead was poured into the sieve, which he shook violently, and the liquid metal fell in drops like rain to the floor of the tower; but in its fall it had recovered its solidified state.

The imaginary person then descended from the tower, and examined some of the shot; and among them Watt saw several that were not either perfectly round, or had tails to them. To separate these from the others, the man removed the shot to an inclined plane; those that were round ran down the plank, while those that were mis-shapen wriggled over the side. A perfect separation was thus effected. This was a lucky dream for Watt, as he sold his patent for 10,000*l.*: and a similar method is still employed by manufacturers; and thus an error of some importance in the construction of balls is entirely prevented in shot.

Another circumstance that deranges the motions of projectiles is, that, after a cannon has been fired several times in succession, it becomes very much heated. During the late wars, this was exceedingly injurious to the French artillery; for many of their guns, which were made of bronze, absolutely melted at the muzzle. Now it is well known, that, when a solid body is heated, its elasticity is partly destroyed; and therefore, if a ball is fired out of a heated gun the elasticity of the gun being diminished, the shot will not go so far as it would otherwise have done.

The greater part of the military projectiles, at the time of their discharge, acquire a whirling motion round their axes,

which arises from the friction exerted between them and the interior of the gun. This motion causes them to strike the air in a manner different from that which they would do, if the motion were simply forward; for the resistance of the air is not opposed to the direct path of the body, and it consequently forces it from the direction it would otherwise take; so that the distance a ball will fly at any given elevation is not a just estimate of its velocity.

The same piece fixed at the same elevation, with ball, powder, and every circumstance as similar as possible, will give very different distances at different times. Although science has offered but little assistance in many parts of gunnery, it has in this instance found a complete remedy in rifle-barrelled guns. These pieces have the inside of their barrels cut with a spiral channel like a screw, only varying from the screw in the particular that its thread approaches to a right line; for it takes little more than one turn in the whole length of the barrel. When the piece is fired, the indented zone of the bullet follows the sweep of the screw, and therefore gains an invariable circular motion round the axis of the piece in addition to the progressive motion which is given to it by the gunpowder. By this whirling motion on its axis, the aberration of the bullet, which is so prejudicial in gunnery, is totally prevented; and as the bullet is subjected to the force of the gunpowder for a longer time, and quits the piece with more difficulty, rifle-barrel guns carry to a much greater distance than common ones.

The compression of air produced by the velocity of the projectile is also another deranging cause. If we suppose a

ball to be projected at the rate of two thousand feet in a second, which is perhaps a fair estimate, it will have to sustain a pressure of more than one hundred weight upon every square inch of its section: and if this be the real velocity of the ball, it must leave a vacuum behind it; for it is well known as a fact in pneumatics, that air cannot rush into a void with a velocity at all approaching to two thousand feet in a second. The pressure exerted against the motion of the ball must therefore be very great.

In the military schools of France, it is assumed that the path of a shot or a bomb would be a parabola, setting aside the disturbing causes; but, under existing circumstances, it is neither a parabola nor any other regular figure. English mathematicians have proved, that the greatest range of a shot is when the piece is elevated to an angle of 45°, but in practice they assume a much less angle. Although the influence of the disturbing causes we have mentioned is very great, yet a shot of twenty-four pounds may be projected out of a cannon with a rate of velocity exceeding two thousand feet in a second.

The velocity of a projectile will, as might be expected, be considerably influenced by the quantity of powder, and the piece from which it is discharged.

The greater the quantity of powder, the greater will be the velocity of the ball. With military men it is not always desirable to give the ball the greatest possible velocity; on the contrary, they generally charge with a small quantity of powder, reckoning one-sixth the weight of the ball for field pieces, and one-third for battering pieces. When battering

in breach, the French artillery will sometimes charge with half the weight of the ball, as they did in the recent siege of Antwerp. But in firing with grape, or from ricochet batteries, they use low charges of powder; in the latter case just enough to throw the ball over the enemy's parapet, that it may go rolling and bounding along, dismounting the guns, and killing the men.

An increased velocity is given by lengthening the barrel within certain limits; but the velocity does not at all depend upon the weight of the gun that discharges it.

ACCELERATED MOTION.

When a body is put in motion, and the force is continued, accelerated motion is evidently produced. A heavy body falling from a height above the surface of the earth, increases its velocity as it approaches the planet. A bullet may be thrown into the air by the force of the arm, and be caught in the hand as it falls; but if it were projected by a musket, it would be impossible to do this; for its velocity would be increased in consequence of the greater space through which it would fall.

When a body is put in motion by any force, the same motion must be continued for ever if uninfluenced by any other force: but if, after a certain interval of time, an equal force be impressed upon it, the motion will be doubled;—if after another interval, the force be again impressed, the motion will be tripled. Now the force of gravitation acting

upon falling bodies is exactly of this kind, only the intervals between the impression of the force must be considered as infinitely small. This leads us to examine what are called the laws of spaces, times, and velocities; that is, the relations which exist between the spaces through which a body moves, the time it takes in moving, and the velocity with which it moves. In examining these relations, we may take the idea of a body falling from a considerable height to the ground, not by any external force exerted upon it, but merely from the gravitation of the earth.

It has been stated, that the attraction of gravitation decreases as the distance multiplied by itself increases. But the greatest height above the surface of the earth on which we are able to observe a descending body is a mere line compared with the radius of the earth. We may therefore in all cases consider the force of gravity acting upon falling bodies as a constant quantity, possessing the same force at all heights, and in every part of its descent.

1. The first law to which we shall allude is, that the velocity increases proportionally with the time.

Let us suppose a body to be three seconds in falling to the ground; the force of gravity will generate the same quantity of motion at every successive period of its descent. At the beginning of the second and third period, it will exert the same force as it did at the beginning of the first; but after the body has been moving one second, it will have gained a certain velocity which must be added to the velocity produced by the attraction of gravitation, and it will give the velocity of the second period which is double that

of the first; and on the same principle the velocity in the third period will be three times that of the first. The velocity of a falling body therefore increases proportionally with the time; or in other words, a falling body has a uniformly accelerated motion.

2. The space through which a body falls increases proportionally with the square of the time.

This law is easily understood. A body falls through a certain space in one second, through four times that space in two seconds, through nine times in three seconds, and so on. It is therefore only necessary to know what space a body falls through in the first second, and we may easily determine the space through which it will fall in any given time.

Let us now examine what relation there is between the spaces through which a body falls in several successive periods. If we suppose the space moved through in the first second to be equal to one, that in the first two will be four, the first three nine, the first four sixteen, and so on. Subtract one from four and the remainder three will be the space moved through in the second period; and four from nine will give five, the space passed through in the third period. In this way we may estimate the actual motion at any moment during the fall; and as a body falls through sixteen feet in the first second when acted upon by gravitation only, the space passed through during any period and at any time may be determined.

These laws may be exhibited experimentally, but not without the aid of a mechanical contrivance. It would be per-

fectly impossible to illustrate any one of these principles by direct observation on falling bodies; for if a body falls through sixteen feet in the first second, it must pass through 256 feet in four seconds. This is a height much too great and the period is much too short to admit of accurate examination. And in addition to this objection it must be remembered that towards the end of the fall the body would have a velocity of 120 feet in a second.

The instrument by which these laws are illustrated is represented at the commencement of this chapter. It was invented in the last century by Mr. Attwood, and is known as Attwood's Machine. The object is to obtain an uniformly accelerated motion of such a velocity that it may be accurately observed. This is done by the following arrangement A wheel is so fixed on its axis as to move with but little friction. Over a groove formed in the circumference of this wheel a silken cord is placed, at the ends of which are metallic cylinders of equal weight. The arrangement is then in equilibrium, for the weight at one end of the cord balances that at the other. To produce motion, a small known weight is attached to one cylinder, which instantly begins to descend. and exhibits the laws we have attempted to explain in such diminished velocities and spaces as give a fair opportunity for experiment. Behind the descending weights a graduated vertical shaft is placed, and a stage to receive the weights (which may be adjusted at pleasure) beneath. A pendulum with an audible beat is also attached to the instrument.

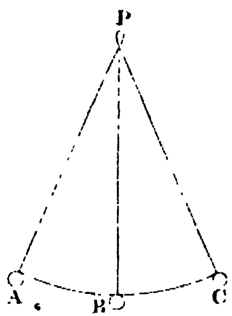
Suppose it were required to prove that the space increases proportionally with the square of the time. The weights

may be so adjusted that they shall fall through one inch in the first second, and they will then pass through four in two seconds, nine in three, sixteen in four, and so on.

THE PENDULUM.

The common pendulum is a heavy ball attached to a slight cord or wire, so formed that it may be suspended to some fixed point. This instrument, simple as it is, has been employed to determine the direction of the force of gravity, and is still used for the measurement of time. If we place the pendulum PB, fig. 4, in any position out of the perpendicular, PA for instance, and let it fall freely, it will descend to B, and, passing this point, ascend on the other side to C, describing an arc AC; it will then begin to descend, and, passing B, ascend again to A.

Fig. 4.



It is scarcely necessary to explain the cause of this motion; for it is evident that when the pendulum descends, its velocity increases till it reaches B, and the accelerated motion thus obtained is sufficient to carry it upwards to C. Gravity therefore is the governing force in the vibration of the pendulum, and in theory it may be considered a perpetual motion. But there are two causes which tend to destroy the motion, and act effectually upon it: these are the resistance

of the air, and the friction of the suspending line upon the point of suspension.

The pendulum employed for philosophical purposes consists of a metallic weight, usually a heavy disc, so sharp upon its circumference that the resistance of the air can have little effect upon it. The fine wire which supports it is attached to a piece of sharp steel, or to a knife-blade which rests on planes of polished agate: with these precautions a pendulum, notwithstanding the resistance of the air and the friction at the point of suspension, will vibrate for many hours.

The time occupied in an oscillation is the same, whatever its extent, when not very considerable; or, in other words, the vibrations are isochronous. This property was discovered by the celebrated Galileo, the philosopher who improved the telescope, discovered the satellites of Jupiter, and did more than any of his contemporaries in extending the boundaries of science, and in making it available to all classes of society. He was attending one evening the service at the church of Pisa, and after the great chandelier was lighted up, it was left swinging: this attracted the attention of the young philosopher, and he observed that the vibrations were isochronous, that is, they were performed in equal times. By the observations he afterwards made on vibrating bodies, he established the truth of this observation, and introduced the pendulum as a means of regulating an instrument for the measurement of time. The reader may easily prove the truth of this law, if he pleases, by counting the oscillations of a vibrating body; and he will find, that whether the pendulum is vibrating in an arc of four or five degrees, or in

one of a tenth of a degree, an equal time is required to perform the oscillation.

Another important principle in relation to the pendulum is, that the time occupied in an oscillation is not dependent on the weight of the ball, the substance of which it is made, or its shape, except so far as regards the resistance of the air. This fact is easily demonstrated; for if we take balls of different substances and sizes, being careful that the pendulums be of equal length, and cause them to vibrate together, it will be seen that the time occupied in a vibration by each is the same. Gravity in its action upon a pendulum causing it to oscillate, exerts its influence upon each atom of the matter which composes the ball; and therefore a single atom suspended at the end of a thread would oscillate with the same velocity as any number of atoms combined together in a body. So also an atom of iron would vibrate with the same velocity as an atom of platinum or of gold; since all masses, whatever their nature, oscillate in the same arc with the same velocity. These observations will tend to illustrate the principle, that gravity acts in the same manner upon all bodies.

It may also be mentioned as a third important law, that the time of the oscillations is as the square root of the length of the pendulum. If we take three pendulums, whose lengths are as one, four, and nine feet respectively, the time required for the oscillation of the second will be twice as long as that of the first, and the time of the oscillations of the third will be three times that of the first, because 1, 2, 3 are the square roots of 1, 4, and 9, respectively.

As the oscillations of a pendulum vary with its length, a certain length is required that it may beat seconds, or, in other words, vibrate sixty times in a minute. The length required in the latitude of London is a little more than thirty-nine inches; but a pendulum that would beat seconds in London would not do so in Paris. The observations made upon the pendulum in the island of Cayenne, by M. Ritcher, first induced philosophers to doubt whether the earth was perfectly spherical, and the instrument has since been used to determine this important problem. M. Ritcher found, that the pendulum of his clock moved at a rate of 2′, 28 a-day less than it ought as regulated by the mean motion of the sun; and, to compensate for this error, he was compelled to shorten his pendulum nearly one-eleventh of an inch in order that it might make vibrations equal to those it made at Paris. This phenomenon is easily accounted for: gravity is always according to the masses; and therefore a double mass will have a double attraction, and a treble mass a three-fold attraction. Now it is found, that a certain pendulum will beat seconds at the poles of the earth; but to make the same pendulum beat seconds at the equator, its length must be altered, which is a proof that the attraction of the earth—that is, the gravity—is not the same at both places. A pendulum which beats sixty seconds in one minute at the North Pole, will not beat so many times at the equator.

All the laws of which we have been speaking are quite independent of the present intensity of gravity; for if this

force were a hundred times greater or a hundred times less than it is, the vibrations would still be isochronous, and the time would still have the same relation to the weight and the length of the pendulum. If gravity were doubled in intensity, the velocity of all falling bodies would be increased, and pendulums would make their vibrations quicker; but the time of the oscillations would still be as the square roots of the length of the pendulums. If gravity were to cease altogether, bodies would cease to fall, and pendulums would cease to oscillate, except by their acquired velocities, which would cause them to continue in motion until the vibrations were destroyed by friction; but there would be no reason why the pendulum should come to rest in a direction perpendicular to the surface of the earth.

All the observations which have been made concerning the laws by which the vibrations of a pendulum are regulated, have reference to a single pendulum, which is an inflexible thread without weight, having a single atom of matter attached. It must be evident, that all the pendulums we are accustomed to use are compound, since it is impossible to fulfil the conditions of the definition; and it is therefore necessary to consider how far this circumstance would influence the laws we have mentioned in their application to practical purposes.

Let us take as simple a case as possible of a compound pendulum. Let us suppose that we can obtain one that consists of an inflexible thread, without weight, but having two heavy molecules attached to it at different distances

Fig. 5.

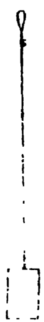
from the point of suspension, as shown in the annexed figure. The molecule, *b* fig. 5, being at a less distance from the point of suspension than the molecule B, has a tendency to vibrate with greater velocity; but as they are joined together, and must oscillate in the same time, the one is retarded, and the other is accelerated, an intermediate velocity being established, and that is the velocity of the compound pendulum. But there is always a certain point in the pendulum which is neither retarded nor accelerated, and performs its oscillations as though it were alone freely suspended from the thread; and that point is called the centre of oscillation, and its distance from the point of suspension is called the length of the pendulum, which is in fact equal to the length of a simple pendulum that would oscillate with the same velocity.

The remarks which have been made upon the simplest of compound pendulums are true in reference to all others; and as we can only employ these, there are considerable difficulties in the way of an effort to determine the intensity of gravity by them. It is not easy to observe with accuracy the duration of an oscillation, or to determine with exactness the length of the pendulum; but both these difficulties have been overcome, and the problem has been frequently solved, first by Borda, in 1790, at the observatory of Paris, and since that period by many English and continental philosophers in various parts of the globe.

The increase or decrease of temperature has a considerable influence on the oscillations of a pendulum. A bar

of metal, which, when cold, will pass easily between two uprights, will not do so when heated red hot, for heat expands solid metallic bodies. For this reason a pendulum, which beats seconds in a low temperature, would cease to do so if taken into a hotter climate; for its length would be increased. This is a fact of great importance in horology, and mechanics have invented various methods of compensating for this alteration in the length of the pendulum, sometimes by making the rod of the pendulum of a substance that would not expand appreciably by heat, and sometimes by contrivances that correct the increase of length that results from a change of temperature. The length of a rod of dry wood is not altered by a change of temperature; and it would be the best possible substance, if it could be perfectly protected from the hygrometric action of the air It is, however, in a considerable degree defended from moisture, when rubbed over with bees'-wax, and makes the most accurate pendulum of this sort when thus prepared.

Fig. 6.

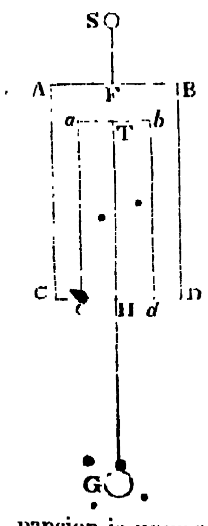


The two best compensation pendulums are the mercurial and the gridiron. The mercurial pendulum, fig. 6, consists of a rod of brass, or other metal, to the end of which a cylindrical vessel containing mercury is attached, instead of a ball. The same increase or decrease of temperature that affects the pendulum rod has an influence upon the mercury in the vessel, and the one corrects the other. If the rod suffers expansion, the centre of oscillation will rise; but if the mercury be duly proportioned, its expansion will be such, that the distance of oscillation from the point

of suspension will be always the same; and therefore, whatever may be the variation of temperature, the pendulum will beat seconds.*

The gridiron pendulum was invented by Mr. John Harrison, and is a very ingenious and useful instrument. It is well known, that the different metals and metallic alloys expand variably under the influence of the same temperature: it is therefore evident, that bars of different metals may be so arranged as to correct each other's expansion when used in the construction of pendulums.

Fig. 7.



Let G, fig. 7, be the ball of a pendulum, and S the point of suspension. A, B, C, D is a steel frame, to which is attached the rod S, F; and *a*, *b*, *c*, *d* is a frame of some other metal, and is attached to the rod C, D at the points *c*, *d*. At T, the rod T, G is suspended, passing freely through an aperture at H. Now, if the temperature be raised, the frame A, B, C, D will dilate downwards, that is, C, D will be carried further from the point S; and if the mass of the pendulum be thus brought downwards, it will no longer beat seconds. But the frame *a*, *b*, *c*, *d* is also expanded, and the expansion is upwards; so that while C, D is lowered, *a*, *b* will be raised. Now, if we suppose *a*, *b* to be raised as much as C, D is lowered, the distance of *a*, *b* from S will remain unchanged. But the increase of temperature which expands

the other part of the instrument, expands the rod T, G, and therefore the distance between G and T is preserved. Now looking at the instrument generally, we observe that SF, AC, TG, when expanded by a rise of temperature, would tend to increase the distance between S and G; that is, the point of suspension and the bob. To prevent this, we must make the frame *c*, *a*, *b*, *d* of such a metal, that its expansion upwards may exactly neutralize the combined downward expansions, and thus the distance between S and G will be preserved.

We have hitherto spoken of pendulums as vibrating in the arc of a circle, but there is a mathematical curve called a cycloid, and if the bob of a pendulum could be made to vibrate in it, its oscillations would all be performed in equal times, whatever the length of the arc.

The cycloid is that curve which is formed by the revolution of any point on the circumference of a circle, the circle itself being made to revolve on a plane. There are some very remarkable principles which might be mentioned in reference to this curve. Of all paths not in a straight line, the cycloid is that in which a body can pass the most readily from one point to another. The right line is of course the shortest path between two bodies, and if a man in a balloon could throw a stone to some point on earth in the shortest path, he would cause it take the direction of a right line, but if he wished to throw the stone in the line of shortest descent, it must be made to move in the cycloidal curve, for it would not only reach its destination sooner, but would strike the object with greater energy. The study of the mathematics has

taught man this truth, and instinct has taught the falcons to fly in this curve; and it is in consequence of their flying in a cycloid when attacking their prey, that they possess so great a velocity, and strike with so great a force.

Ingenious mechanics have attempted, for the reasons already stated, to cause the pendulum to vibrate in this curve; but hitherto with little success; for so few of the practical difficulties have been removed, that it is not probable this desirable object will ever be accomplished.

CENTRE OF GRAVITY.

There is a point in every body, whatever may be its form, on which, if a force were exerted equal to the sum of all the forces acting on the component parts, it would be in equilibrio: this point is called the centre of gravity.

It must have been observed, that bodies will not rest indifferently upon any point. A square block for instance is supported with difficulty upon one of its edges, and if we should succeed in placing it in that position, the slightest agitation of the surface on which it rests will cause it to fall upon one of its sides, in which position in will remain quite stable. The body was not firmly supported in the first instance, because the centre of gravity was not sustained.

The equilibrium of any body resting on a surface, or point, may be stable, instable, or neutral. A body is always stable when the centre of gravity is below the axis of the body, and instable when it is above the axis. If a body in

equilibrio be moved from one position to another without attempting to return to any particular place, it is said to have a neutral equilibrium. This is the case with a perfectly round homogeneous body: it may be placed upon any part of its surface without attempting to change its base.

The centre of gravity of some bodies may be very readily determined. Take a piece of card-board and cut it into the shape of a triangle. Suspend it from any two points successively, and each time mark the situation of the vertical line as given by a plummet. The point where these lines intersect each other is the centre of gravity; and each line is called a line of the direction of the centre of gravity, for the centre will be found in some part of it.

The centre of gravity of homogeneous bodies of regular shapes is always in their centres. To find the centre of gravity of a parallelogram, it is only necessary to draw two diagonal lines, and each divides the figure into two equal parts. The point of their intersection is the centre of the figure, and the centre of gravity.

The centre of gravity of cylinders with parallel bases, whether hollow or solid, is in the axis, and in that part of the axis which would be cut by dividing the cylinder into two equal parts. The centre of gravity of a body is not always in the body. In the instance of a hollow cylinder it is in the axis; and in a circular ring in the centre from which the circle is drawn.

In considering the equilibrium of a body on its centre of gravity, it is usual to suppose it perfectly rigid, having neither elasticity or compressibility, or in other words, that

its particles are in a state of absolute immobility in relation to each other. But this is not by any means the case. A perfectly regular homogeneous bar of iron may have its centre of gravity in the middle, but when it is supported on that point, it will bend, because of its elasticity; the centre of gravity will, in consequence, be moved, and the equilibrium be destroyed. In theory this may be disregarded, but in practice must be estimated.

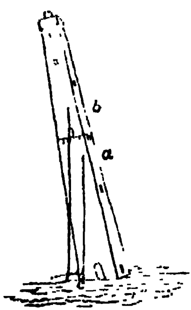
We have spoken of three conditions of equilibrium as resulting from the support of the centre of gravity; stable, instable, or neutral. Take a circular disc, and attach to it a hand which is able to move freely round, and may be placed in any position. Now in order that the needle may be in equilibrium, it must be placed in a line of the direction of the centre of gravity. When it is in the vertical line, but above the axis, the slightest alteration of position will entirely destroy the equilibrium. But if it be placed beneath the axis, it may be removed on either side of the line, and it will quickly regain its position. In the former case we have an instance of instable, in the latter of stable equilibrium.

A body is in a state of neutral equilibrium when the centre of gravity is at an equal distance from every part of the surface. A sphere, if formed of uniform materials, will be in a state of neutral equilibrium, for its centre of gravity would be equally distant from every part of the surface, and therefore, if set in motion the centre of gravity will be always parallel to the plane on which it moves. But if the sphere be composed of a substance of unequal density, or if the centre of gravity be not in the centre, then its stable equili-

brium will be in that point where the centre is nearest to the plane on which it rests.

The stability of equilibrium will also greatly depend on the extent of base, and upon the position of the perpendicular line drawn from the centre of gravity. As long as this line falls within the base equilibrium will be maintained, but as soon as it is without, the equilibrium will be destroyed. It must, therefore, follow that the greater the extent of the base, the more the centre of gravity may be moved without destroying the equilibrium.

Fig. 8.



Let fig. 8 represent a tower: *a* is the centre of gravity; *a c* is the line of direction, and it falls within the base: therefore the tower is in equilibrium, because the centre of gravity is supported. But add to the height of the tower, so that *b* may be the centre of gravity, and the tower must necessarily fall.

The feats of rope dancers and other mountebanks are performed by keeping the centre of gravity within a small base. A tree is supported because the line of direction falls within the extent of base formed by its roots; but the branches will, from their elasticity, often bend with their own weight, and the tree in consequence be placed in a state of such instable equilibrium that it is easily uprooted by a violent wind.

When a body is supported on two or more points, the line of direction must fall between them. A carriage for instance.

being supported by two wheels, the line of direction must fall between them, or the equilibrium will be destroyed. It is exceedingly dangerous to load a coach, or a waggon, to a great height, for if it should have to pass over any place where the wheels on one side are much above those on the other, the line of direction may be thrown out of the base, and the carriage must be overturned.

The centre of gravity in the human body is always in the pelvis, between the hips, the ossa pubis, and the lower part of the back bone. When the arms or legs are thrown upwards, the centre of gravity is slightly elevated. If a man has lost a leg the line of direction falls upon his foot; a man with two legs has it between his feet. It is because the base is larger in the latter instance than in the former, that the equilibrium of a man with two legs is more stable than that of a man with one. When we walk the line of direction is thrown from one leg to the other, and the centre of gravity is raised as the leg is elevated, and consequently passes through a gentle undulation. But when there are no knee joints, the centre of gravity is more elevated, and describes arcs of a circle.

Quadrupeds do not raise either pair of legs together, for the centre of gravity would then be unsupported, and the animal would fall. By raising one of the front, and one of the hind legs together, the centre is supported, and the stability of the animal secured. Many other examples of the facts we have stated in relation to the centre of gravity might be mentioned, but these will probably be sufficient to illus-

trate the general principles of this important branch of mechanics.

ACTION AND REACTION.

Having illustrated the first two of those principles called the laws of motion, we may now proceed to demonstrate the third:—"Action must always be equal and contrary to reaction; or the actions of two bodies on each other must be equal, and directed towards contrary sides."

The whole doctrine of action and reaction may be said to depend on the inertia of matter. All matter being in itself passive and under the influence of forces, we may always predict the state that will be induced by a knowledge of the forces which will operate. This statement is beautifully illustrated by the results of the impact of bodies under all circumstances. There are three ways in which bodies may be brought into collision, and an example of each may be given.

When a body in motion impinges on a body at rest, the motion is divided between the two, according to their masses. Let us suppose that a ball moving with a velocity equal to two, strikes another of equal mass, the motion will not be destroyed but equally divided, and both will move with a velocity equal to one.

If the ball at rest should be four times as large as that in motion, the motion will still be divided between them according to their masses; that at rest will take four-fifths, and the other retain one-fifth.

To show how these results may be anticipated from the inertia of matter is hardly necessary. There is a certain amount of motion produced, and it can neither be increased nor decreased by impact except so far as is required to overcome the friction of the body at rest, and the resistance of the atmosphere. "Motion is not adequately estimated by speed or velocity. For example, a mass A moving at a determinate rate has a certain quantity of motion. If another equal mass B be added to A, and a similar velocity be given to it, as much more motion will evidently be called into existence. In other words, the two equal masses A and B united have twice as much motion as the single mass A had when moving alone, and with the same speed. The same reasoning will show that three equal masses will with the same speed have three times the motion of any one of them. In general, therefore, the velocity being the same, the quantity of motion will always be increased or diminished in the same proportion as the mass moved is increased or diminished. On the other hand the quantity of motion does not depend on the mass only, but also on the speed. If a certain determinate mass move with a certain determinate speed, another equal mass which moves with twice the speed, that is, which moves over twice the space in the same time, will have twice the quantity of motion. In this manner, the mass being the same, the quantity of motion will increase or diminish in the same proportion as the velocity." It is, then, to the momentum of a body that we must refer for a proper estimate of the quantity of motion.

The transfer of motion from one body to another may also

be seen in the impact of two masses moving in opposite directions.

Let us take the simplest case, two equal masses having the same velocity and moving in opposite directions. At the moment of collision each parts with its motion, the one neutralizing that of the other, and producing rest. That which is moving towards the right is met by that moving towards the left, and receives an impact in the opposite direction equal to its own proper motion. Each ball in fact is in a condition resembling that of a point acted upon by two equal forces in opposite directions.

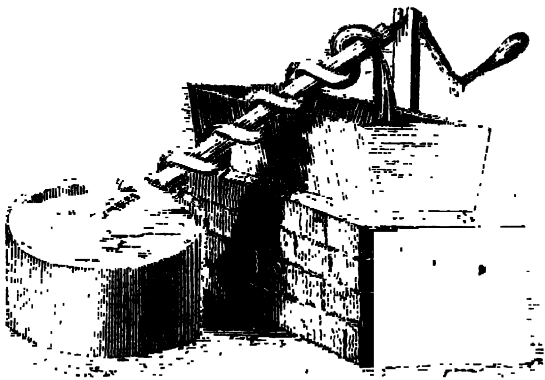
If the two masses have not the same momentum, motion is continued, but the direction in one mass is changed. Let A and B be two balls, the momentum of the former being 16, that of the latter 12: the motion of B is neutralized, and twelve parts of the motion of A; four however remain, which are proportioned between the bodies, according to their masses, and they consequently move together in the direction that A had previous to contact.

There is yet one other case of action and reaction, that in which two bodies are moving in the same direction. It is not however necessary to give examples of this, as the principles referred to in the others may be easily applied by the reader; and we will pass on to mention a few familiar illustrations.

That the momentum depends on the mass and velocity conjointly, may be proved by the effects produced by bodies which differ in bulk and motion. A ship of war floating down a river has but little velocity, yet from its bulk

or mass it has so great a momentum that a boat sailing with considerable velocity might be crushed by collision. So a man with a heavy load walking slowly strikes against any obstacle with a force as great, or perhaps greater, than if he were walking very fast without a load. And on the other hand a lad whose bulk of body is but small may have a great momentum from the velocity with which he is running.

Almost every person must remember instances in which he has suffered from the practical illustration of action and reaction. Standing perhaps in the streets of London, he has suddenly found his centre of gravity disturbed by a violent blow from some clumsy porter, whose momentum, under such circumstances, always sufficient, was greatly increased by the burden he carried. At other times he may have inadvertently come into collision with a hurried messenger running at full speed. The violence of the shock that would be received in the latter case is much greater than might be anticipated, for when two persons meet each other in this way, each receives a blow equal to the sum of the forces. Supposing for instance that two persons moving in opposite directions come in contact, one walking at the rate of four miles an hour, the other running at the rate of six; each will suffer the same shock as if the other had rushed upon him when at rest, at a rate of ten miles an hour.



CHAPTER II.

HYDROSTATICS.

INTRODUCTORY REMARKS.

THE sciences which teach the properties of liquids, and the forces produced by them when at rest and in motion, must be of the greatest importance to every state of society, and especially to one so far advanced in the arts and comforts of life as that which exists among many nations in the present day. What would be the condition of London or any other large mercantile town, without its pipes, pumps, water engines, and canals. The advance of practical mechanics has in some measure destroyed the necessity of an entire dependance upon water as a mechanical power and a means of communication between distant places, but it can never render the knowledge of hydrostatical principles of secondary importance.

The explanation of the phenomena presented by liquids, of which water is a type, belongs to three sciences;—Hydro-

statics, Hydrodynamics, and Hydraulics. The science of Hydrostatics relates to the equilibrium of fluids. Hydrodynamics to the motion of water, and the nature of the forces producing that motion. The science of Hydraulics explains the construction and uses of those instruments in which water is either the moving power or the weight. It will not be necessary for us in the remarks to be made in this chapter, to support a systematical arrangement. Our only object is to state the elementary facts of these sciences in as simple and intelligible a manner as possible.

A fluid is said to be a collection of material particles which may be considered as infinitely small, and as moving freely among each other in every direction without friction. There are two kinds of fluids; gases and liquids, and they differ in physical constitution. A gas or vapour has a great tendency to expand when its temperature is increased, or the pressure acting upon it is removed; it is consequently called an elastic fluid. Liquids have not this property, the two antagonist forces, attraction and repulsion, are so excellently balanced that their bulk is not changed by any alteration in their physical condition—they are consequently called non-elastic fluids.

A great deal has been said and written by philosophers concerning the nature of fluidity, and much more will probably be advanced before any conclusive evidence of truth can be obtained. The cause of fluidity has been determined. Heat is the great agent by which every change in the constitution of bodies is performed. But the nature of fluidity can only be ascertained by discovering the actual form and con-

dition of the ultimate particles of matter when in that state. It is a common opinion that the particles of fluids are spherical, hard, and with polished surfaces. This supposition has been entertained because an assemblage of spheres will touch each other in the fewest possible points, and consequently have the least friction, for friction is according to the surfaces; and also because a greater number of spheres may be packed in a given bulk, than bodies of any other form. Allowing that the particles have polished surfaces and are hard, the theory will be still insufficient to explain the nature of fluidity. The spherical form is not under all circumstances the most susceptible of motion. A series of marbles upon a floor have, it is true, a great susceptibility to motion; but after having carefully placed together nine or twelve, pile others upon them, and another series on them: there will then be little tendency to motion, for the marbles of every series above the base will fall into the cavities between the contiguous ones of those which are below. The circular form of the ultimate particles, so far from accounting for fluidity by a diminution of friction, would be sufficient of itself to destroy that equable motion for which all fluids are remarkable. Fluidity is occasioned by heat, and both liquids and gases derive their extreme mobility from the repulsive force with which the particles act on each other, and not from their spherical form.

In a subsequent part of this work we shall have occasion to speak fully of the agency of heat in producing fluidity, and it will not therefore be necessary to say much on the subject at present. It is well known that nearly all solid bodies

may be rendered fluid by heat, and in the process they absorb, if we may be permitted to use the term, a large portion which is appropriated to the constitution of the new condition of matter, and is not sensible to the touch or to the thermometer. There are, however, some substances which are permanently fluid at common temperatures, but may be reduced to the solid state by a reduction of sensible heat. The fluidity of these substances also arises from the possession of constituent caloric.

Liquids and gases are distinguished from each other in physical properties, by the different degrees of compression of which they are capable.

The elastic fluids, that is the gases and vapours, may be easily forced, by pressure, into a less bulk than they assume under ordinary circumstances. If a condensing syringe be attached to a strong metallic vessel, a much larger quantity of air than it holds under the common pressure of the atmosphere may be forced into it. This process may be carried on until the expansion of the contained air shall be equal to many atmospheres, and at last overcome the cohesive force of the vessel.

Let us now see what is the result with water. Fill the brass vessel and syringe used in the former experiment with water, and then attempt to compress the liquid in the vessel by forcing into it some of that in the syringe. The attempt is made in vain, for the piston rod will now refuse to go down, being resisted by the water in the vessel. From this simple experiment we ascertain that water is not capable of compression under common forces, and in practice it may be consi-

dered altogether destitute of that property. Recent experiments have proved that when water is subjected to enormous pressure, it may be forced into a smaller bulk; but how great that pressure must be, may be deduced from the fact that the Florentine academicians filled a hollow globe of gold with water, and by a great mechanical force endeavoured to introduce a screw into the vessel, but the water, rather than suffer compression, passed through the pores of the metal. From this result, says a gentleman, well acquainted with the science we are explaining, it was inferred that water is incompressible; but there are a variety of reasons for concluding that no substance possesses absolute incompressibility, for the most dense solid bodies are known to have pores; and that there are interstices between the particles of water is obvious from the possibility of adding solid matter to it without increasing its bulk. Besides which the Florentine experiment was inconclusive, or rather, would seem to lead to an opposite conclusion, because it must be recollected that the introduction of the screw changed the interior figure of the globe, and diminished the volume of the fluid it contained; and it was therefore incumbent on the academicians to have shown that the quantity of water which exuded through the globe was equal to this diminution of volume; for if the quantity were less, it is obvious that the water must have undergone some degree of compression, and consequently the inference cannot be relied on.

In the present day we need not refer to the expetiment of the academicians to determine whether water be capable of compression. The experiments of Canton and Perkins clearly

establish the existence of this property, though it is so small in degree that we may still term liquids incompressible fluids, for they are strictly so under all common pressures.

THE SURFACE OF A LIQUID IS ALWAYS LEVEL.

It is one of the most obvious and important principles of Hydrostatics, that the surfaces of liquids always maintain a perfect level. Those who have stood by the sea side when the water has been undisturbed by the passing breeze, or the noisy gale, must have observed the beautifully level surface which it presents. When the winds are hushed and no agitating force is upon it, there is no attempt in one part to rise and in another to fall. The bark that plows its furrow on the surface is unable to give permanence to its path, for the adjacent waters flow in and fill up the channel. So when the waters of the ocean are disturbed by the wind which passes under their surface, they are restless under its restraint and every falling wave seeks to arrange itself in a horizontal plane. These appearances result from what is called the general tendency of liquids to maintain their level.

But when we speak of the surface of liquids as being perfectly level, we do not mean that the ocean is an horizontal plane, for it is influenced by terrestrial gravitation which does not act in parallel lines, and therefore it must necessarily partake of the general convexity of the earth. The centrifugal force has also some influence in the production of this effect. When the surface of any mass of water is extensive, the convexity must be estimated, but when only of slight extent it may be considered as a plane.

In cutting canals which extend over a large track of country it is necessary to take into calculation the deflexion from the horizontal plane which is about eight inches in a mile. This deflexion increases as the square of the distance, and consequently will be 8 × 4, or 32 inches at a distance of two miles, and 8 × 9, or 72 inches at a distance of three miles, and so on.

When we investigated the conditions of equilibrium of solids, it was stated that a body acted upon by two equal forces in opposite directions, is kept at rest. Thus a body may be influenced by the force of gravity, and the resistance of the plane on which it is supported. These forces exerting an equal power in a contrary direction, the body is kept in equilibrium. We may also suppose the same substance to be acted upon by other forces, and still it will continue at rest if they be only equal and opposite. But it is otherwise with a fluid, it has only one condition of equilibrium, and that is when the force is impressed in every direction. If we suppose a fluid to be acted upon by two forces it is evident they can only produce motion, that is an elongation of the mass in a direction at right angles to the forces. Thus if a bladder containing water be pressed in two parts, opposite to each other with forces which are equal, the compression will cause the bladder to extend in a direction at right angles to the points of pressure. A fluid, therefore to be in equilibrium must be pressed with equal force in every direction, and consequently the surfaces of fluids at rest must always be perfectly level.

It is by the operation of this principle that we are

able to convey water in pipes from one place to another, if no part of the pipe rise higher than the surface of the water in the reservoir. Let us for instance fill with water a vessel, having first attached a small tube, of greater length than the vessel, and let this tube be furnished with a stopcock. If we make a communication between the tube and the cylinder by turning the stopcock, the water will be driven into the former with considerable velocity, and owing to the momentum, it will for an instant rise somewhat higher than the level of its source, but soon subside and settle on a level with the fluid in the vessel; and the same will be observed at whatever degree of elevation the tube may be placed. If we take a tube having a number of bends, instead of one that is straight, and place the finger upon the end, when the stopcock is turned, the fluid will only rise to a certain height, less than that which is necessary to complete the level, and governed by the elastic force of the condensed air; that is, it will rise till the elastic force of the condensed air is a counterpoise to the pressure exerted by the liquid column. When the air is allowed to escape, the fluid will rise higher, but will not rise to its proper level, on account of a portion of air being still left in the sinuosities of the tube. Now this is precisely what happens in the common water pipes of our cities, and is the real cause of the obstruction to the flow of water, which sometimes happens; on account of the lightness of air it always ascends to the upper bends of the pipes, and these are the places, therefore, where it must be let off. This has been accomplished by an arrangement proposed by Mr. Stevens, who applied a float

which acts upon a lever. When water is in the pipes the float is raised, and the lever closes the aperture. When air is present the float is low, and the lever opens the aperture, giving out the enclosed air.

It has been stated that the Romans were unacquainted with the law, that fluids rise to the level of their source, and consequently with the use of pipes. But this is certainly an error, for we have no right to deduce such a supposition from the fact of their having built large aqueducts; and independent of this, the principle is stated by some of the ancient philosophers [1], and several of the Latin poets [2] have alluded to water pipes as being employed. The real cause of their unfrequent use is perhaps to be found in the circumstance that the materials for their construction could not be readily obtained.

Professor Leslie, in his Natural Philosophy, makes the following remarks upon the use of pipes among the Romans. In the Physical Cabinet of the University of Edinburgh is now deposited a specimen of ancient leaden pipe lately brought from Rome, where it had been dug up among the ruins of the palace of the Cæsars. It bears an inscription in raised letters intimating the name of the plumber, and the year of the reign of the Emperor Domitian. Though only sixteen inches long, and nine and half in girt, it weighs twenty-two and a half pounds avoirdupoise; so that the lead must be very nearly half an inch thick. The pipe is slightly curved and rudely formed into merely a flattened oval, two

[1] Pliny, Palladius, Vitruvius, &c.

[2] Horat. Epist. i. x. 20. Ovid. Metam. iv. 120.

inches and a half broad, and one and a quarter wide; the joining edge being filled by a quantity of melted solder run along both inside and outside. The section corresponds to a circular orifice of one inch and seven-eighths diameter.

In the construction of canals the engineer has mainly to consider the law to which we have just referred. Canals appear to have been formed in China and Egypt at a very remote period. The Romans learned the art of constructing them from the Egyptians, and introduced them in various parts of their extended dominion. This people introduced them in England in the fenny districts east of the river Trent. At first they were only formed upon extended levels, and land carriage was consequently necessary to connect them with each other or with rivers. This great inconvenience led to an enquiry whether some means might not be adopted by which an ascent could be overcome.

The first lock appears to have been erected in the year 1488, upon the Brenta nigh Padua, and immediately after that period the two canals at Milan, between which there was a fall of nearly thirty four feet were joined by means of six locks.

When the communication between navigable streams is interrupted, whether by intervention of rising ground, cataracts, or rapids, great inconvenience is necessarily experienced. Sometimes the goods must be carried from one place to another. In many parts of North America merchandise and boats are thus conveyed, as at the falls of Mohawk to Wood Creek; and in Scotland from Loch Lomond to Loch Caterine. Sometimes however the empty boats may be

drawn up a rapid, or the rapids may be rendered navigable by contraction. Another plan is to stop the water of a river for a time, and then to let it off so as to occasion an artificial flood.

The land carriage is also prevented by *ponts aux rouleaux*. or inclined planes with rollers at short distances, over which, by means of a water wheel, the boats are lifted up to the edge separating the two waters, and afterwards launched into the stream again.

The importance of canal navigation is now decreasing rapidly in consequence of the establishment of railways. There are some situations in which an inland communication is most advantageously established by canals; but generally speaking, canals are less desirable than railways. The expense which attends their formation, and the difficulties often experienced in procuring a full and regular supply of water, are obstacles to their establishment. In the construction of canals and railways it is a principal object to avoid the friction experienced upon common roads. Canal transit has the great inconvenience of a resisting medium acting against the draught in the inverse ratio of the velocity of the boat. The speed of canal navigation must always be limited, in consequence of the destruction of the banks from a rapid motion. This must be a great obstacle against the conveyance of passengers; and as the speedy transit of goods as well as passengers, is now of importance, there can be no doubt that canal navigation must ultimately give way to the establishment of railways. The comparative facility of loading and unloading carriages is also favourable to the choice of railway traffic.

It has long been a maxim with those best acquainted with commercial affairs, that the amount of trade is always in proportion to the facility of intercourse; and as the necessity for labour increases with the prosperity of the manufactures, the establishment of railways can only be considered as one of the best practical results of science, and that which will ever distinguish the present age. The expense attending the formation of railways, and the imperfection of the early plans delayed their introduction in this country; but now that the principles are thoroughly understood, and experiment has improved the early practice, the time cannot be far distant when all the large towns in the kingdom will be provided with the easy communication they offer.

But although the practical importance of Hydrostatics, and especially of that principle to which we have referred, may become of less importance so far as concerns the construction of canals as a general means of traffic; yet there are situations in which railways cannot be established with propriety, and canals must be the only means of communication. There are many purposes independent of this, to which the great law of fluids maintaining their level may be applied; we shall however content ourselves by the mention of one, the conveyance of water for the supply of large towns. A short abstract of the history of the water-works in the city of Edinburgh may be interesting. A more detailed account of this and other similar works may be found in Mr. Matthews's Hydraulia.

"The city of Edinburgh being chiefly erected on eminences, many of its inhabitants formerly experienced great diffi-

culties in obtaining a plenty of good water for common domestic use, and hence originated an attempt, in 1681, to procure a supply that should be adequate to their wants. The method adopted for this purpose consisted of a train of leaden pipes, three inches in diameter, and 13,520 feet in length, to convey it from the village of Comiston to a reservoir constructed on Heriot's ridge. As these pipes eventually proved too small for their object, the defect occasioned the laying down of another train, in 1722, having a diameter of four inches; but during the subsequent fifty years, the population progressively increased, and consequently required a proportionate addition to the supply, which induced the magistrates, in 1787, to adopt a main of iron pipes, five inches in diameter. Though this measure had the effect of augmenting the quantity of water; nevertheless the introduction of various improvements and the erection of buildings, rendered it necessary to have recourse to some other springs at a greater distance from the city. In 1790 an additional main of iron pipes, seven inches in diameter, was therefore laid down, to convey water from Green Craig to the Castle Hill, at an expense of 20,000*l.*; and this source furnished about 80,640 cubic feet in the course of every twenty-four hours."

In the year 1810 it was found that the supply of water was not sufficient to satisfy the wants of the inhabitants of Edinburgh, and a committee was formed to consider what means could be adopted to provide the quantity required. After an accurate examination of the surrounding country it was determined that the water must be brought from

the Crawley Springs, on the south side of the Pentland Hills, seven miles distant from the city; and that, to secure a sufficient quantity of water, under all circumstances it was desirable to collect that issuing from some springs on the north side of the Pentlands by lateral conduits. The spring head is 360 feet higher than the highest street in Edinburgh. The cistern at Crawley Springs is forty-five feet long, fifteen wide, and six deep. Connected with this are various reservoirs for the supply of different parts of the town; one of them is on Heriot's Green, having a circular form, and containing a basin thirty feet in diameter, with a depth of ten feet. It is about 270 feet below the fountain head. Another reservoir, constructed on the Castle Hill, has a length of forty-three feet, by a width of twenty-eight feet, with a depth of seven feet six inches; the site of this is about 230 feet below the fountain head, and its altitude forty feet above the other. It supplies the Northern districts of Edinburgh."

From this account it may be gathered that the work is but an application of the principle, liquids will always rise to the level of their sources. Give water a liberty of motion through a pipe which is always at a level beneath the bottom of the reservoir in which it is contained, and it will flow away; but if the pipe rises to the same height as the top of the reservoir, the water will rise in the pipe to the same level as it has at that time in the reservoir, although the bulk at one terminus may be much greater than at the other. So in the conveyance of water from any place for the supply of a town, it is only necessary that the source should be at an

equal or slightly greater elevation than the highest place to be supplied.

We shall now close our remarks upon that law which causes liquids to maintain their levels, by extracting a passage from the book already quoted, which may be useful to those who have occasion to apply the principle in the construction of water-works.

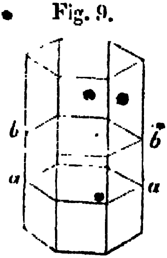
"The water is conveyed from its source by a train of strong iron pipes, which vary in their capacity, diminishing as they approach Edinburgh, from twenty to fifteen inches in diameter. At the fountain head, those of twenty inches commence the series, and continue for a considerable space, when pipes of eighteen inches diameter are introduced to the end of the first 18,300 feet; of which the descent is about sixty-five feet. For the remaining part of the main, pipes of fifteen inches are employed, and the fall of this space is 286 feet, in the length of 27,900 feet. In some parts they have an undulating course, and ascend and descend twenty or thirty feet. The main passes through two tunnels,—one of them excavated in the solid rock of the Castle Hill, for a length of 1740 feet, and 120 feet below the reservoir;—the other being conducted under Heriot's Green, seventy or eighty feet below its surface, and having a length of 2160 feet. The reservoir on Castle Hill communicates with that on Heriot's Green, and large pipes branch off from both, for the plentiful supply of the city, in every direction. The strength of the pipes is adapted to sustain a pressure equal to a column of water 800 feet high."

PRESSURE OF LIQUIDS.

It is scarcely necessary to remark that fluids, as well as solids, are influenced by the force of gravity. If this were not the case rain would not fall, and the atmosphere would not be confined around the earth. It seems almost as unimportant to state that fluids gravitate in their own element. To prove this fact, take a glass bottle properly fitted with a metallic cap, and air tight. Suspend this bottle to one arm of a delicate balance, and carefully weigh it when immersed in water. Then fill the bottle with some fluid, and weigh it again in the same manner. It will be found that a great increase of weight in the opposite scale will be necessary to establish the equilibrium. From this simple experiment it will be quite evident that a fluid has weight in its own element, for the increase observed can arise from no other cause than the weight of the liquid, as an equal quantity of the water into which it is immersed must be displaced in both experiments.

Now as fluids are heavy bodies they exert a pressure upon the vessels which contain them, and that pressure will be according to the altitude of the column. Thus if we pour water into the cylindrical vessel fig. 9, to the height *a a*, and it press upon the bottom with a force equal to one pound; then an equal quantity rising to the height *b b* will exert the same pressure, and

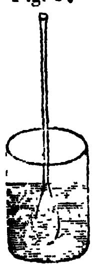
Fig. 9.



the bottom will consequently have to sustain their united force.

That this statement may not be misunderstood it will be necessary to explain at once that the pressure exerted by a fluid upon the bottom of a vessel, does not depend upon the quantity of fluid it contains, but upon its height. This proposition has been called the Hydrostatic Paradox, and yet nothing is more evident or more simple. Practical proofs are constantly observed by every one. When a house is supplied from a reservoir perhaps containing an immense volume of water, the little pipe that supplies it, is filled, or may be filled to the same level as the water in the reservoir The same thing may be observed in a common garden pot filled with water; the column contained in the spout is on a level with that in the vessel itself. Now in both these instances it is evident that the small column supports the pressure of that of the larger, proving that the force exerted is according to the altitude of the column, and does not in any degree depend upon the quantity. It is the same with elastic fluids. The barometer is a column of mercury acting with the same pressure on the surface of the samefluid as a column of the atmosphere having the same base.

Fig. 10

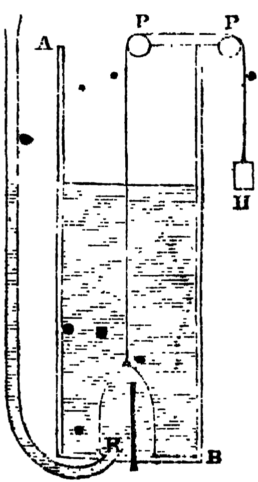


But the pressure of fluids is in every direction, upwards and laterally as well as downwards. Take a small bladder, fig. 10, and attaching it to the end of a glass tube, fill it with a coloured fluid. Now immerse the bladder in a cylindrical vessel of water, and every portion of its surface is immediately brought under the influence of an

external pressure, which forces the coloured fluid up the tube. This can only result from a pressure in every direction equally, for as we have already stated, a condition of equilibrium in fluids can only be produced by equal forces in every direction. But it may be also observed that the greater the depth to which the bladder is sunk, the greater will be the external pressure upon it, and the increase will be in proportion to the depth, for the surface of the coloured fluid will at every instant exactly coincide with that of the water in which it is immersed.

A very ingenious instrument has been invented to show that the upward and downward pressure of liquids is the same, and at the same time it proves that the pressure is according to the height of the column, and is not dependant on quantity. Let A B, fig. 11, be a cylindrical vessel of glass, and T a glass tube inserted and opening into the bottom. R is a small receiver, to which is attached a string passing over pullies P P, and exactly counterpoised by the weight H. *p* is a small tube passing through the bottom of the vessel, and of such a height as to reach nearly to the top of the receiver when fixed at the bottom. Introduce the receiver into the cylinder, and press it firmly to the

Fig. 11.

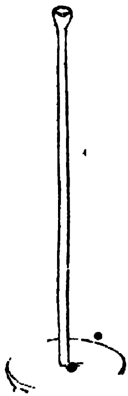


bottom, so that it may be air tight, and hold it in that position while water is poured into the vessel to any height, H, for instance. The downward pressure of the fluid will now keep it in its place. Then pour water into the tube T, and it will rise into the receiver which covers the lower end, and as this is filling, the air must be allowed to escape from it by removing a small plug at the lower end of the tube *p*. The plug being fitted again into its place, continue to pour water into the tube T until it shall stand a little above the level H, and the receiver will then immediately rise to the top of the fluid in the cylinder, for the pressure upward is greater than that downwards. The communication is then opened between the lesser and greater columns, and they will instantly adjust themselves to the same level. We thus prove by a single experiment that the pressure is according to the height of the column, and also that the upward and downward pressures are equal.

It is also true, and may be proved by experiment, that the lateral pressure is equal to that which is exerted upwards and downwards, and consequently increases with the height of the column. Many persons suppose that flood gates have to resist a force produced by the quantity of water, against the progress of which they are acting. But this is not true, for the pressure in this, as in other instances, is according to the height of the water.

As the pressure of fluids is according to the height of their columns, we may easily obtain an enormous force from a comparatively small quantity of water or any other

Fig. 12.



liquid. The Hydrostatic bellows, fig. 12, is an example. This instrument consists of two circular boards united by leather, bladder or indian rubber cloth—the latter is to be preferred—in the same manner as a pair of common bellows. A narrow brass tube, four or five feet long, is fixed perpendicularly to the upper board, so that water may be poured through it into the interior of the instrument. Now when water is poured into the tube pressing upon that contained within the boards, the pressure of the column is communicated to the surface of the water which fills the bellows, and the boards are separated with a force equal to the difference between the area of the boards and the tube. Thus if the area of the boards be one hundred times greater than that of the tube, a pound of water in the tube will support a hundred pounds on the upper board.

It is almost impossible to imagine the amount of power which may be obtained by the application of this principle. The late Mr. Bramah invented an instrument called the Hydrostatic Press, in the construction of which the law is beautifully applied. The power of this instrument is so great that with a small machine, which may be easily carried about by a lad, and may be used on a table, a man may cut through an inch bar of iron as easily as he could cut card-board with a pair of scissors.

The same power is, we have no doubt, active, past all calculation, in producing change on the physical condition of

the earth. Imagine a vertical fissure to be formed in a rock, communicating with a small horizontal reservoir of water, and let this fissure be filled with rain water, or that produced by the melting of snow; who can estimate the violence of the force which will be instantly called into action? The pressure in every direction would be so great that the solid rock might be shaken by it, or torn asunder by its uncontrolled energy.

In calculating the influence of physical agents in the production of change on the surface of the earth, we are too liable to estimate their power by a false comparison with the phenomena we witness upon the laboratory table. The extent of natural agents are seldom fully estimated, and indeed they cannot be, from the trivial exhibitions of their power presented to our view. The power and unlimited extent of their operations can only be traced by man in detail, and that insulated view he takes is insufficient to give an adequate conception of their energy. By the use of a large instrument a man can separate, with little physical exertion, substances which the combined strength of hundreds could not tear asunder. But shall we compare this with those vast operations constantly going on in the mineral kingdom, by the influence of the same principle? Philosophy may teach the laws by which the various kinds and conditions of matter are governed, but the largest and most powerful instruments employed by a man when compared with those fully operating in nature are but as toys which amuse our simplicity and gratify our self-esteem.

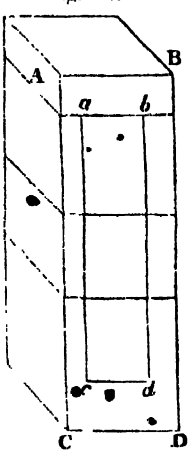
It is not a difficult task to discover the total amount of

pressure by a column of water upon any surface. We have proved already that the amount of pressure is governed by the height of the fluid. The entire height may be divided into any number of equal parts, ten for instance and the pressure of the uppermost may be represented as equal to one. Then the entire pressure will be the sum of the series, that is, the first and last terms added together and multiplied by half the number of terms.

There is always a point, on every surface which has to bear a fluid pressure, where, if an adequate force be applied, and in a contrary direction, the entire pressure may be supported. This point is called the centre of pressure.

This fact, and the situation of the point, may be shown by an instrument represented in fig. 13. A B C D is a vessel, the front and back of which are formed of wood, and the two sides of glass. In the front is a moveable disk, *a b c d*, attached by leather or indian rubber, and made air-tight, forming a large valve. As soon as water is poured into the vessel the valve is forced outwards by the lateral pressure of the fluid. Now let the vessel be filled to the height *a b*, that is to the top of the valve. There will be some part of the valve to which a force may be applied so as to exactly counterpoise the fluid pressure. If a piece of wood be pressed against the top of the valve, the lower part will be forced outwards; if against the bottom,

Fig. 13.



the upper part will be forced outwards. But if the bar of wood be moved downward, and applied at two-thirds of the depth, the valve will be closed through its whole length. This is the situation of the centre of pressure.

THE EQUILIBRIUM OF FLOATING BODIES, AND BODIES PLUNGED IN LIQUIDS.

From the existence of gravitation as a force acting on all bodies, it is certain that any substance raised above the surface of the earth must fall, unless supported by some force capable of counteracting the influence of gravity. There are in nature many phenomena which appear to be contrary to that law by which matter in all its states is governed; such as, the suspension of clouds in the air, the rise of vapour, and the floating of large bodies on the surface of water. These however are not instances of the invasion of any law governing material existence, but bring to our notice the causes by which one force may be modified by the interference of another. The phenomena of bodies sinking and floating in fluids depend on a principle which has been called, the law of Archimedes, because discovered by that philosopher.

This principle, or law, may be thus stated:—a body plunged into a fluid, loses a part of its weight, equal to the weight of the fluid it displaces; and the proposition is equally true whether the fluid be a liquid or a gas. Imagine a large vessel full of water, and let there be a cube in the interior of

the liquid, having the superior and inferior faces in the same horizontal plane. It is evident, upon the principles of Hydrostatics, that the lateral pressures are equal and contrary; and consequently destroy one another; and also, that the superior face supports a downward pressure equal to the column of water above it, while the inferior surface sustains an upward pressure equal to the column beneath it.

A body, when placed on a liquid, is subject to two opposing forces; one its weight, which tends to sink it, the other the upward pressure of the medium. If any substance be immersed and the two forces be equal, it will remain in equilibrium; if the pressure of the fluid be greater, it will float, that is, it will be repelled to the surface; if the weight has the advantage, it will fall to the bottom. Let us, says a celebrated French philosopher, imagine any volume of water, a sphere for instance, to have the radius of a metre; and let the molecules of water actually contained in this volume be congealed so as to form a solid instead of a liquid, supposing that in the act of congelation they neither approach to nor recede from one another, but preserve exactly their positions and distances. Under such circumstances the solid sphere would remain suspended and at rest, in the same manner as the liquid sphere did previous to its congelation; for the adherence we have established between the different molecules can neither sustain them nor cause them to fall. This solid sphere has therefore lost its weight since it does not fall, and it has lost it because surrounded with a fluid which presses it on every side.

From these statements it will appear that when a solid

sinks in a fluid it does so because it has a greater weight than the volume of water it displaces. The quantity of any fluid displaced by the immersion of a solid in it must depend on its bulk, without reference to its weight. If two equal cubes, one of marble and the other of metal, be successively immersed in water, the liquid will rise in both cases to the same height, although one is much heavier than the other. When the weight of a solid is less than that of an equal bulk of the liquid, the solid will float; and when the two are equal, it will be in equilibrium, resting in any position where it may be placed. In fact, the latter is a case similar to that in which a volume of water is supposed to be solidified without any change of bulk or weight.

The stability of a floating body depends on another cause. The only condition of stability is that the meta centre should be beneath the centre of gravity. This meta centre is that point where the axis of the centre of gravity of the fluid intersects the axis of the fluid it displaces. When the meta centre coincides with the centre of gravity the body is indifferent to motion, when above it will upset. In the construction of ships and other vessels intended to float on water, this law must be considered and practically applied; if it be not, there is a great danger that they will be in an instable state, and the vessel will upset.

Fishes have a capability of rising, sinking, or floating in water at pleasure. They must therefore have a means of increasing or decreasing their weight, so as to make the bulk of their own bodies of greater or less weight than the volume of liquid they displace. This they are able to do by altering

the size of the swimming vessel, which has different forms in different species, but is always so placed as to lighten the upper, and to give additional weight to the lower parts. In this manner the condition of stability is secured. According to the curious observations of M. Biot, says an eminent French teacher, the gas of the natatory vessel is not atmospheric air; it is almost pure azote in those individuals which live near the surface, and is composed of nine parts of oxygen and one of azote in those which live at a depth of from 1000 to 1200 metres. At 8000 or 9000 metres these gases would be as dense as water, and the natatory vessels would be useless for equilibrium.

In fishes that are taken at a depth of 1000 metres, the gas of the natatory vessels is under a pressure of water equivalent to 100 atmospheres, and consequently at the surface it must tend to take a volume 100 times greater; and we may observe that all the muscular energy of the fish is insufficient to retain it. When it escapes, the neighbouring organs are expanded, especially the membrane of the stomach, which is then so dilated that it forms a kind of balloon. From these facts we may judge that every region of the sea has its peculiar inhabitants, suited to the depths at which they live, as well as climate.

SPECIFIC GRAVITY.

From what has been already stated in reference to floating bodies, it will be most evident that bodies of equal magnitudes, but of different densities, when immersed in the same

fluid, lose equal parts of their weight. If for instance we take a cube of plaster and a cube of metal, both cast in the same mould, they will be found to have very different weights, but will lose exactly the same amount of weight when immersed in water, and that amount will be exactly equal to the weight of the cube of water they displace. As a collateral proof of this statement, take a cube of plaster so large as to balance in air the cube of metal, and having suspended these to the arms of a balance, immerse them in water at the same moment. The lead will now appear to be heavier than the plaster, for being of less bulk it will lose less of its weight.

If this be the true explanation of the result, we may, when we weigh bodies in liquids form a comparison between their densities, or in other words we may determine their specific gravities. If we weigh a body in the air, we only obtain its gravitating power, without reference to its density. We know that the bulk of a pound of cork is much greater than that of a pound of lead, but we have no means of ascertaining their relative densities. To determine this, that is, their specific gravity, we must find the weight of the volume of liquid they displace.

To ascertain the specific gravity of any body, it is necessary that we should compare it with some other body whose density we are to take as unit. Thus a piece of copper may be heavy, and we may speak of its weight absolutely and positively; but when we say that it is heavier than another body, we institute a comparison, and it is convenient to have some common unit to refer to. If we say that gold is heavier

than lead, and lead is heavier than tin, and tin is heavier than water, we point out, it is true, their specific gravities, but it is much more convenient to compare them all with water, and to say that gold is nineteen times heavier, lead eleven times, and tin seven times heavier than water.

The standard of specific gravity must be of a fixed and unalterable nature, or if it does change, the laws of those changes should be well known, and all casualties concerning it should be well defined. Philosophers have, with one consent, fixed upon water as the most appropriate liquid, and in all tables of specific gravity the specific gravity of water is denoted as one.

In endeavouring to ascertain the specific gravity of bodies with great accuracy, it must not be supposed that water, as it is commonly met with, is an appropriate standard. The specific gravity of sea water and river water are very different. The waters of the ocean are loaded with a variety of saline substances, muriatic acid, and soda. Magnesia, iodine, and other bodies are found in either chemical or mechanical combination, so that if the water be evaporated a very considerable residue is left. River water does not hold so much saline matter in solution, but it is for the most part more or less turbid, from the mechanical suspension of heterogeneous substances. Its specific gravity is likewise much deranged by air which is held in solution. This however is an impurity very common to most kinds of water, as may be seen by placing a glass of cold spring water under the receiver of an air pump. Upon exhaustion air bubbles will be plentifully evolved from the liquid.

It might be supposed that spring water would, from the circumstances under which we meet with it, be much purer than river water, and such in fact is often the case. But this greatly depends on the character of the strata through which the water percolates; for if sulphate of lime, muriate of soda, or any other substance soluble in water happens to be in its course, it is immediately taken up, and necessarily renders the water impure. Some of the deepest wells in London however afford water that is very free from all these impurities, and such as may, after boiling, be used for roughly estimating specific gravities. Rain water, or newly fallen snow, affords a liquid which must be in a great degree devoid of saline matter.

Snow water will be much purer than rain water, for rain water is generally gathered from the roofs of houses, and is liable to be impregnated with many impurities. Nor is the rain water that falls in the vicinity of large towns so pure as the rain water of the country, as in the former the drops have to descend through clouds of smoke charged with ammoniacal matter, which is not the case in the open country. Both rain water and melted snow are exceedingly rich in oxygen and in carbonic acid gas, which they absorb from the atmosphere.

As distilled water has an uniform density, philosophers take it as their unit of specific gravity. In distilling rain or spring water the gaseous matter will first separate because of its volatility, it is then followed by pure water and the saline and other fixed impurities will remain in the still. Chemically speaking however, the process of distillation is not

competent to effect the total separation of all impurities from water. A certain action of the boiling fluid is liable to carry off much impurity, and in Sir H. Davy's experiments it was found that boiling water would even dissolve a portion of glass if distilled in vessels of that substance. If water were very susceptible of compression the density or specific gravity of the distilled water would change with the density or specific gravity of the air, and the unit of our tables would be perpetually altering. But the compressibility of water is so small that, under the alteration of a few ounces in the pressure of the air, its bulk will remain the same ; and for this reason barometric alterations are not taken into the account in ascertaining specific gravities.

The alteration of the temperature of the circumambient air is much more likely to disarrange our experiments. Heat acts upon air as it does upon all other bodies, by increasing its bulk, and consequently lessening its specific gravity. If we take a glass tube and pour into it some hot water, and then add some of a much lower temperature, the cold will be seen to displace that which is hot, and cause it to float on the top.

Tables of the expansion of water, as occasioned by the addition of certain degrees of heat, have been prepared, and these are useful in calculating the necessary compensation for the alteration of the specific gravity. But the shortest and simplest method is to bring the water, whose density you take as unit, to some fixed temperature agreed upon by common consent, that is, 40° of Fahrenheit's thermometer. The reason for selecting this particular temperature is, that,

although we may consider it as a general law, that the absorption of caloric causes a body to contract in its dimension, yet when water is cooled below 40° of Fahrenheit, it begins to dilate, and continues to do so, until it freezes at 32°.

At the temperature of 40° Fahrenheit therefore the water is at its greatest state of condensation, and consequently at its greatest specific gravity. At the temperature of 40° Fahrenheit a cubic foot of water weighs exactly 1000 ounces avoirdupoise.

The elements for ascertaining the specific gravity of solid bodies are, first, to weigh the substance in air, and then in water: then divide the weight of the substance in air by the loss it has experienced in water.

It has already been stated that a body immersed in water displaces a volume of that fluid exactly equal to its own, and it loses weight exactly equal to the weight of the volume it displaces. We therefore find by this method the weight of the body and the weight of a volume of water equal in bulk to that of the body. These two weights compared together give the relation between the specific gravity of water, which we suppose to be known, and that of the given body, by making the following proportion, in which 1.0000 represents the specific gravity of the water. The weight of the volume of water displaced by the body is to the weight of the body as 1.0000 to a fourth proportional representing the specific gravity of the body, for the specific gravities are as the weight of equal bulks. Therefore the specific gravity of the fluid is to that of the water as the weight lost in the fluid is to the whole weight.

It may now be useful to mention certain precautions which must be attended to, in ascertaining these weights with precision.

Attention must be paid to the line which connects the body with the pan of the balance. It must be of a particular thickness, it must have no great weight, and be impenetrable to water; a single thread of silk such as produced by the silk worm is the best material that can be used, provided it is not too slender to support the suspended body: a fine wire of platinum or silver may be employed with advantage if it can be obtained sufficiently thin, and a horse hair is a very unexceptionable substance. In the hydrostatic balance case we usually find a little platinum cage suspended from a thin wire of the same metal; this may be at once plunged into the water and the substance put into it.

Bubbles of air are very apt to adhere to the substance when it is plunged into water, these of course derange the weight, and must be carefully guarded against. Air will cling to the surface of bodies with great tenacity even in vacuo, and on plunging a piece of metal into water, charged in this manner with air, the surface of the metal is soon covered with bubbles. A thin capillary tube of glass, or a horse hair, may be used to disperse these globules.

When the suspending line is sunk into the water, there is a slight friction between it and the liquid, and the level of the latter is depressed round the line. This must in some degree disturb the accuracy of the results. This depression, however, only exists around such substances as have but little attraction for water, and such in particular as are of an

oleaginous or greasy nature. If a thread be used, it is on the contrary very liable to be wetted by the oscillations of the balance to some distance above the level of the water, and thus there may be a considerable addition to the apparent specific gravity.

When we wish to take the specific gravity of a substance that is acted upon chemically by water, it is evident that though we may ascertain its true weight in the air, we cannot determine its weight in water. The only method that can be practised under such circumstances is, to ascertain its specific gravity with reference to some other liquid, whose specific gravity is known, and then, by the common rule of proportion, to find its specific gravity with respect to water. Spirits of wine, or an essential oil may be used for this purpose.

The term specific gravity of a body is nothing more than the comparative weight of any body and water; we may find the specific gravity of any fluid, by weighing a quantity of it against an equal quantity of water. For this purpose a bottle is made which will hold just a thousand grains of distilled water, and is hence called the thousand-grain bottle. It has a ground stopper, which is perforated through its length by a longitudinal hole. If the bottle be filled with water, and the stopper put into its place, the excess of water will pass through the hole in the stopper, and may be wiped away. The instrument-maker adjusts the bottle in the first instance, by grinding away portions of the stopper until the capacity of the vessel is just one thousand grains.

To ascertain the specific gravity of any liquid, it is there-

fore only necessary to fill the bottle with that liquid, and then to weigh it. Care, however, must be taken not to hold the bottle in the uncovered hand, or the heat communicated would sensibly derange the success of the experiment. It must also be dried with a clean cloth, and particular attention must be paid that no small hairs or other impurities adhere to the surface. In every new experiment the bottle must be accurately cleaned and washed, that the relics of former operations may not cause erroneous results.

In the absence of the thousand-grain bottle, it is easy for the chemical student to manufacture one before the flame of a blow-pipe. For this purpose a bubble must be first blown, and a piece of thermometer tube may be used as a stopper. The capacity of the bulb may be brought near to the thousand grains by having it sufficiently large at first, and then if any part be heated in the spirit lamp, it will contract in cooling, and the capacity become less. When it has fallen below the thousand grains, by a very slight quantity, the final regulation is to be obtained by grinding the stopper.

Bubbles of glass are prepared for finding the specific gravity of fluids. The specific gravity of these is written upon them, and they are so arranged as to form a regular series.

We now come to one of the most delicate yet important operations of Chemistry, and of Natural Philosophy, the method of ascertaining the specific gravity of a gas. A gas. from its high elasticity and consequent expansibility, is subject to many changes unknown to solids and liquids. Alterations in the temperature, pressure, and moisture of the air,

which is the standard of comparison, must be taken into the account.

To determine the specific gravity of gas, take a thin glass globe with a stopcock, weigh it as accurately as possible, exhaust the air, and weigh it again. The loss of weight is now equal to the weight of the air drawn out. If the glass be then filled with any gas, and weighed again, the increase of the weight, above the weight when exhausted, will be the weight of the gas required.

Now it is evident, that the volume of gas that enters the globe is exactly the same as the volume of air drawn out by the pump; if therefore we divide the gas by the weight of the air, it will give the specific gravity of the gas. It is, however, necessary that the experiment should be rapidly and carefully performed, that errors may not creep into the calculation.

These remarks upon the method of determining the specific gravity of substances, will, it is hoped, be of some value to the practical student; to the general reader they must be uninteresting. It is, however, of but little use to attempt the study of any branch of natural philosophy without experiments; and as the subject of which we have been speaking requires some illustration, we have felt ourselves at liberty to introduce a few observations for the guidance of the manipulator.

HYDRODYNAMICS.

THE MOTION OF LIQUIDS.

We have hitherto entirely confined our attention to the pressure exerted by liquids, and the phenomena presented by them when at rest. A few remarks may now be made upon the cause of their motion, and the laws which govern their velocity. This is, as all persons must admit, a complicated and difficult subject; and one which will not perhaps be very interesting to that class of persons for whom this work is chiefly intended. It is, however, a branch of science of the utmost importance, and cannot be passed over without some notice. "The theory of Hydraulics," says Dr. Young, "has never been carried to a very high degree of perfection upon mathematical foundations alone; nor has it hitherto, even with the assistance of experiment, been rendered of much practical utility." Without the assistance of mathematical analysis, little can be done towards the explanation of the theory of Hydraulics; and as we have no opportunity of entering at this time into such an enquiry, our observations must be confined to a few statements illustrative of the facts determined by experiment.

There is, as we have already stated, only one condition of equilibrium in a fluid body, and that is, when it is acted upon by equal forces, and in every direction. If such a condition be established, and a force at any one point be withdrawn, motion will be produced. A volume of water in any open reser-

voir will be at rest so long as the vessel shall remain perfect on every side, for it suffers resistance at every point. But form an aperture at any point, and the condition of equilibrium will be destroyed. The science of Hydrodynamics or Hydraulics, then, comprises not only the laws which regulate the motion of liquids through pipes and channels, rivers, and canals; but also the discharge of liquids from reservoirs through orifices and tubes.

Feeling strongly the difficulty of presenting to our readers a distinct, and at the same time a comprehensive view of hydraulic phenomena, we cannot avoid quoting the remarks of Dr. Lardner, a writer who has deservedly the character of being able to explain mathematical and physical principles in the style of a popular writer or a profound mathematician, with equal facility.

"It is the peculiarity of this branch of hydrostatics, that, from various causes, the phenomena actually exhibited in nature, or in the processes of art, deviate so considerably from the results of theory, that the latter are of comparatively little use to the practical engineer. They also lose a great part of their charm for the general reader, from the impossibility of producing from familiar objects, whether of nature or art, examples appositely and strikingly illustrative of the general truths derived from scientific reasoning. It must not, however, be supposed that the results of such investigations are false, or that the science itself, or the instruments by which it proceeds, are defective. The difficulty here lie rather in the peculiar nature of the phenomena, and the number of disturbing causes which render them incapable of

that accurate classification and generalisation, which is so successfully applied to almost every other department of physical science.

"The only really useful method of treating a branch of knowledge so circumstanced, is to accompany a very concise account of such general principles as are, at least, inapplicable to practice, by proportionately copious details of the most accurate experiments which have been instituted, with a view to ascertain the actual circumstances of the various phenomena."

Guided by these opinions, in which we fully coincide, it will be our object to explain, with as much simplicity as possible, the facts and principles discovered by experiment, but at the same time introducing only those steps in the investigation which are, according to our opinion, requisite for a popular illustration of the subject.

THE MOTION OF A LIQUID THROUGH AN ORIFICE.

When a horizontal aperture is formed in the side of a vessel filled with water, the liquid will be put in motion, and issue from the opening with a certain velocity. The force by which the motion is produced will be proportional to the depth of the opening below the surface of the liquid. No new force is called into operation for that which now causes motion was before resisted by a pressure on the spot where the aperture was formed. It must, therefore, be evident that some proportion may be found between the depth of the aper-

ture below the surface of the liquid, and the quantity of water flowing from it in a given time, for certainly the rapidity of efflux increases with the depth of the aperture.

But before we proceed to examine this part of our subject, it is necessary to remark, that the discharges of a liquid from a horizontal orifice are nearly proportional to the area of the orifices, whatever may be their forms; the height of the fluid being in every case the same. This being kept in mind, it is not difficult to prove, by experiment, that when a liquid is flowing from a horizontal aperture, the height is as the square of the velocity with which it flows: a fact clearly demonstrated by Bossut's experiments.

Take any vessel that has an orifice in one of its sides, an inch or two above the bottom, and pour water into it to the height of one inch above the opening. Now the pressure of the fluid being at this point unsupported, the water will flow out with a certain velocity, say at the rate of five feet in a second, that is, so long as the surface continues of the same height above the orifice. Supposing that it were required to give the water a double velocity, the height of the surface above the aperture must be four times greater, that is to say, it must be four inches. The reason of this is evident: as the height is increased, the velocity of efflux is increased, because the pressure is increased in the same proportion. It might, therefore, be supposed that a double height would be sufficient; but this cannot be the case, for as double the quantity of water is to be put in motion in a given time, and as it is at the same time to have a double velocity, the force must necessarily be four times greater. If it were required to give

the same quantity of water a double velocity, a double force would be sufficient, but as the quantity must increase with the velocity, the force must be four times greater; and that force is pressure, which is according to the height of the surface. Hence then it will appear, that to obtain twice the velocity, we must have the surface four times higher; for thrice the velocity it must be nine times, and so on.

The velocity of a liquid, flowing from an aperture in the bottom of a vessel, has an increase, governed by the same law as would regulate the velocity of a falling solid. The same law is in operation when the aperture is in the side of the vessel. In order to establish, says Dr. Lardner, the remarkable fact that the velocity with which a liquid spouts from an orifice in a vessel, is equal to the velocity which a body would acquire in falling unobstructed from the surface of the liquid to the depth of the orifice, it is only necessary to prove the truth of this principle in any one particular case. Now it is manifestly true if the orifice be presented downwards, and the column of fluid over it be of very small height; for then this indefinitely small column will drop out of the orifice, by the mere effect of its own weight, and therefore with the same velocity as any other falling body; but as fluids transmit pressure equally in all directions, the same effect will be produced, whatever be the direction of the orifice. Hence it is plain that the principle just expressed is true, when the depth of the orifice below the surface is indefinitely small; and since it is true in this case, it must, according to what has been already explained, be also true in every other.

It may also be worthy of notice, as a fact resulting from what has been already said, that when a fluid issues from an orifice it has always a velocity sufficient to make it rise vertically to the same height as the surface of the fluid above the aperture. Take a vessel, and having formed orifices in it at different heights, fix a jet in each so that the liquid may rise vertically. This being done fill it with water, and keep it full. From each jet a column of water will be thrown, and each will be thrown to the same height, that is, to the level of the surface of the water. From that orifice, which is only one inch beneath the surface, the water will be thrown to the height of one inch, while that which is thirty will eject a column of thirty inches.

From these considerations we must be impressed with the extreme mobility of all liquids. To give motion to a fluid mass, it is only necessary to make a slight derangement of one of its molecules, and the motions which result throughout the whole mass will be so various, modified by different causes, that it is almost impossible to imagine the complication of the phenomena that will be thus produced.

It may also be observed, that the sides of the vessels containing liquids sustain an external and internal pressure—there is a force resulting from the pressure of the fluid which is outward, and another from the atmospheric pressure which is inward. When, therefore, an opening is formed in the side of a vessel, the water will flow out, if the pressure from within be greater than that from without. This must always be the case in an open reservoir, for the pressure on the exterior of the vessel is that exerted

by the atmosphere alone, while that on the interior is the combined force of a liquid mass, and the atmospheric column.

When water issues from a small hole in the bottom of a vessel, it descends in nearly a vertical direction, and the surface deviates but little from a horizontal plane. At a distance of two or three inches from the bottom, the particles turn from the vertical direction, and come from all parts with a motion more or less oblique towards the aperture. The same takes place when the water escapes from a hole in the side of a vessel. The tendency of the particles of the liquid towards the orifice is a necessary consequence of their great mobility, for they are necessarily directed towards that part where they meet with least resistance.

At a small distance from the bottom of the vessel, the water forms itself into a kind of funnel, the lowest point of which corresponds with the centre of the aperture. When a liquid flows through an orifice in the side of a vessel, a kind of half funnel is formed, beginning where the surface nearly touches the hole. It is probable that this funnel shape is formed as soon as the water begins to flow from the orifice, but it is not observable until the surface of the liquid is brought near to the bottom of the vessel.

The reader will do well to study, in connexion with what has been here said on the motion of a liquid through an orifice, the thirty-sixth proposition of Newton's Principia, a work which must be read by all who wish to obtain more than a general knowledge of the physical sciences. For the benefit of those who are not able to refer to this work we

may be permitted to quote a passage from that proposition which relates to our present enquiry.

"The particles of the water do not all of them pass through the hole perpendicularly; but flowing down on all parts from the sides of the vessel, and converging towards the hole, pass through it with oblique motions, and in tending downwards meet in a stream, whose diameter is a little smaller, below the hole itself, its diameter being to the diameter of the hole as 5 to 6; or as $5\frac{1}{2}$ to $6\frac{1}{2}$, very nearly, if I took the measures of those diameters right. I procured a very thin flat plate having a hole pierced in the middle, the diameter of the circular hole being $\frac{5}{8}$ parts of an inch. And that the stream of running water might not be accelerated in falling, and by that acceleration become narrow, I fixed this plate, not to the bottom, but to the side of the vessel, so as to make the water go out in the direction of a line parallel to the horizon. Then, when the vessel was full of water, I opened the hole to let it run out; and the diameter of the stream, measured with great accuracy at the distance of about half an inch from the hole, was $\frac{21}{40}$ of an inch. Therefore the diameter of this circular hole was to the diameter of the stream very nearly as 25 to 21. So that the water in passing through the hole, converges on all sides, and after it has run out of the vessel, becomes smaller by converging in that manner, and, by becoming smaller is accelerated, till it comes to the distance of half an inch from the hole, and at that distance flows in a smaller stream, and with greater celerity than in the hole itself, and this in the ratio of 25×25 to 21×21, or 17 to 12 very nearly, that is, in about the subduplicate ratio of 2

to 1. Now it is certain, from experiments, that the quantity of water running out in a given time through a circular hole made in the bottom of a vessel, is equal to the quantity, which, flowing with the aforesaid velocity, would run out in the same time, through another circular hole, whose diameter is to the diameter of the former as 21 to 25. And therefore that running water, in passing through the hole itself, has a velocity downwards equal to that which a heavy body would acquire in falling through half the height of the stagnant water in the vessel, nearly. But then after it has run out it is still accelerated by converging, till it arrives at a distance from the hole that is nearly equal to its diameter, and acquires a velocity greater than the other, in about the subduplicate ratio of 2 to 1; which velocity a heavy body would nearly acquire, by falling through the whole height of the stagnant water in the vessel."

Hence then it will appear, that when a liquid flows from a vessel through a circular orifice, the stream will, in some measure, mould itself into the form of the orifice, and pass to some distance before it divides and falls in drops. Between the surface of the vessel and the point of division, the stream has a constant form, and from the rapid successive motion of the particles appears to be a solid with a polished surface. After leaving the aperture, the stream diminishes to a certain limit, and then increases until the stream divides.

The fact that the quantity of a liquid issuing from an orifice, is proportional to the depth, may be proved approximately by the following experiment. Fill a vessel with water,

and let it run out through an aperture in the bottom, observing the period occupied in the escape of the fluid. Then fill the vessel again, and keep the surface at the same height, by continually supplying a quantity equal to that which escapes, and it will be found that, in the same time, nearly a double quantity will be discharged.

THE MOTION OF LIQUIDS THROUGH TUBES.

When fluids spout through jets or tubes, they move in that curve called a parabola, the curve itself varying according to the direction of the jet.

Venturi, when considering the resistance exerted by fluids moving against solid bodies, discovered an important fact, that fluids pass with greater rapidity through tubes than they do through apertures. Suppose a vessel containing a known quantity of water to be emptied in a certain time by running through an orifice. Fill the vessel again, and let a tube of the same diameter be fitted into the opening, and the vessel will be emptied much sooner than in the former case.

By an extensive series of experiments it has been found that the discharge of fluids by tubes of different sizes is nearly in proportion to their bore. A liquid sometimes passes through a cylindrical tube of the same diameter as the orifice in which it is fixed, without touching the surface, and sometimes the tube is filled. In the first instance there is no variation in the velocity or quantity, but in the second both are increased. The quantity in the first is to that of the

second as 100 to 133, provided the diameter of the tube be nearly a quarter of its length [1].

We might now proceed to an investigation of the resistance of fluids, for although their particles have an easy motion among each other, upon other substances friction is produced, and consequently there can be no unresisted motion. A river, however slow its progress, insensibly destroys its banks and removes the light materials thrown over its bottom. Water cannot glide over the most polished surfaces without friction, and when moving with considerable velocity produces the most destructive effects upon the solid strata of the earth. We shall not, however, attempt in his place an explanation of these phenomena, and especially as we have had occasion to refer at large to the subject in our "*Mineral and Mosaical Geologies*;" but pass on at once to the explanation of a few Hydraulic Machines.

ARCHIMEDES' SCREW.

The instrument represented at the commencement of this chapter is said to have been invented by Archimedes, for the purpose of draining the low grounds of Egypt; but it was also used for drawing water from the holds of vessels: and according to Athenæus, the name of this philosopher was venerated by the ancient sailors for the benefits they derived from his invention. The instrument consists of a pipe wound spirally round a cylinder. It is extremely simple in

[1] Pouillet's Elémens de Physique.

its construction, but some difficulty has been felt in explaining the theory of its action.

We may understand the operation of this instrument in raising water, by considering the motion of a ball placed in it under different circumstances. If the cylinder be placed in a vertical position, and the ball be put into the upper end of the spiral tube, it will gradually pass through all the windings of the screw when the tube is made to revolve on its axis. If, on the other hand, the cylinder be placed in a horizontal position, the ball will descend through a portion of one spiral and there remain at rest, until the axis of the cylinder is thrown into an oblique position, when the ball will necessarily descend from one point to another, until it falls from the opposite extremity.

But let the lower extremity of the spiral be plunged into water; and that portion which is directed upwards will necessarily be filled with the liquid descending by the force of its own gravity. When the cylinder is turned, the water moves forward in the canal to occupy that part which becomes lower than the mouth of the tube; and by a continued rotation the liquid advances up the spiral, being constantly thrown into the lowest parts.

There is, however, as Mr. Barlow has stated, an important difference with reference to the computed effect of this machine between the water and the ball, for the water by reason of its fluidity after having descended by its gravity to the lowest point of the demi-spire, rises upon the contrary side to the original level, on which account more than half one of the spires will soon be filled with the fluid. In illus-

trating the theory of Archimedes's screw, this fact must be taken into consideration.

WATER WHEELS.

Water is frequently applied as a mechanical power; it is then commonly made to act by its impulse, or weight, on the circumference of a wheel, the force being generally at right angles to the radii. Motion being thus produced, it is transmitted and regulated by machinery, so as to act in the manner most consonant with the effect to be produced. We have thus mills of various mechanical operations deriving their action from a single force, and always in the same direction, and yet performing motions in different and even in opposite ways.

Water wheels are of four kinds, the undershot, overshot, breast, and horizontal; and these are variously constructed according to the situations in which they are to be employed.

OVERSHOT WHEEL.

Fig. 14.

The overshot wheel is represented in fig. 14: it consists of a rim so arranged as to be divided into open cups or buckets, and connected with the axis by a series of spokes. The mouths of all the buckets have precisely the same direction, so that each one is in its turn equally exposed to the mechanical action of the water. When the mouth of the bucket comes immediately before the horizontal mill-course, the

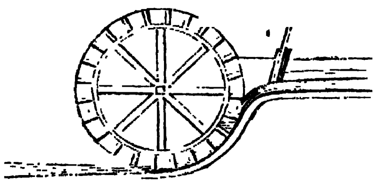
bucket itself is filled with water, and by its weight tends to give the wheel a motion in the direction of the stream. This force is aided by the impetus of the flowing water, so that a constant rotatory motion will be kept up proportioned to the quantity and velocity of the stream. As the bucket, which we have supposed to be filled with water, descends from its vertical position towards the horizontal, the influence of the weight increases upon the principle of the lever. We may suppose the vertical line bisecting the wheel to represent the fulcrum of a lever, and it will then appear that the loaded bucket will have the least influence from its weight, when on the summit of the wheel, and the greatest when on a line at right angles to the axis. Every one knows that the power of a water wheel greatly depends upon the form of the bucket, and the reason of this will be evident from what has been just stated. One of the main objects of a mill-wright will be to form the buckets of such a shape that the water in each may be brought over a space equal at least to one-fourth of the circumference without losing any portion of the liquid it contains. When the loaded bucket is at its greatest height, it will have a minimum influence in producing the revolution of the wheel, but the force will increase in proportion as it is brought nearer to that part of the circumference most distant from the vertical line. After passing that line, its power upon the wheel will be decreased, not only because it is brought nearer to the vertical line which we have supposed to represent the fulcrum, but also because a large quantity of the water which represents the weight, must be lost whatever may be the form of the bucket.

It will then be understood that the force of an overshot wheel depends upon two principles, first, the impetus that is given to it by the impact of water upon the highest point of its circumference, and secondly, upon the weight of the buckets, which increases from the vertical line to the horizontal. Those of our readers who may be unacquainted with the mathematical principles of the lever, will understand the statements we have made from an acquaintance with the action of the common steel-yard, which is a machine suspended upon a point and having two unequal arms. To the end of the shorter a hook is attached, upon which the article to be weighed is carried, and over the longer a determined weight may be moved at pleasure. According to the distance of the weight from the point of suspension, will be its value, the force increasing with its distance from the fulcrum. This principle may be further illustrated to our juvenile readers by the well-known game of see-saw. When a plank is placed upon the edge of a piece of timber, or brick work, in such a manner that it shall be in equilibrium, that is, remain in a horizontal position, it will move upwards and downwards by a force applied alternately to either end, but if a heavy man should sit upon one end and a child upon the other, that end upon which the former is placed will preponderate. Yet it would be easy to establish an equilibrium between the two portions of the plank, for if the man should approach nearer to the fulcrum, he might so adjust his position as to make his weight just balance that of the child. It will then be perceived that the weight increases in proportion to the length of that arm of the lever

from which it is suspended, and hence the weight of a bucket must increase as it descends from the vertical to the horizontal position, being in the one case at the least, and in the other at the greatest possible distance from the fulcrum.

THE UNDERSHOT WHEEL.

Fig. 15.



Round the circumference of the undershot wheel, fig. 15: a number of plane surfaces are fixed at equal distances, and at right angles to the face of the wheel. These are called float boards, and were formerly placed perpendicular to the rim of the wheel, or in other words, were projections from the radii, but it is now found to be more advantageous that they should present an acute angle towards the stream. The action of this wheel may easily be understood, for the motion is produced solely by the impetus of the water, and its construction is more simple than that of the overshot wheel.

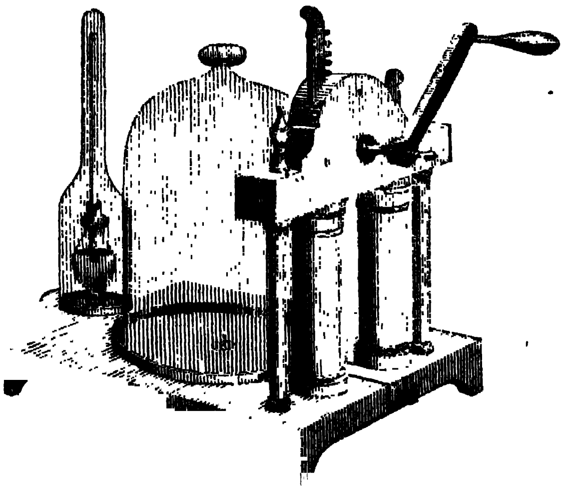
BREAST AND HORIZONTAL WHEELS.

The breast wheel is acted upon by the stream, at a point intermediate between the upper and under part of the wheel, nearly on a level with the axis. It is furnished with float boards like the undershot wheel, but these move in a curvilinear millcourse, so that they act in the same manner as

buckets, the water giving motion by its weight as well as by its impetus.

The horizontal wheel is constructed in the same manner as the undershot wheel, and the millcourse for both is formed in nearly the same manner. The principal difference is, that one is placed horizontally, the other vertically, and the only object of the former is to save machinery by attaching the mill stones at once to the vertical shaft of the wheel.

The subjects we have attempted to explain in this chapter, are, perhaps, more intricate and difficult to be understood than many branches of experimental philosophy: our object has been to remove the difficulties which would most discourage the beginner, and prepare him for a more extensive investigation of the science. In the space to be devoted in this work to the separate branches of experimental philosophy, it is not possible to give more than a sketch of those facts which may be considered to form the base of the sciences.



AIR PUMP.

CHAPTER III.

PNEUMATICS.

ELASTIC AND NON-ELASTIC FLUIDS.

PNEUMATICS (from πνεῦμα, breath) is that science which teaches the mechanical properties of the elastic fluids, of which air is the type.

In the last chapter, the physical difference between liquids and gases was stated and explained. All gases and vapours are capable of being compressed into a smaller space than they occupy under the ordinary pressure, and have also the

property which enables them to expand, and assume the same bulk when the force that produced the compression is removed. Liquids, on the other hand, are incapable of compression except under enormous forces, and their elasticity is so small, that the removal of all the pressure to which they are subject on the surface of the earth, would not make any appreciable difference in their bulk. There is, therefore, a propriety in dividing fluids into two classes; the gases and vapours being elastic, and the liquids non-elastic.

As it is our principal object to explain in this chapter those mechanical properties which are common to all elastic fluids, it is necessary to choose one as the type of the whole. To ascertain these properties we must have recourse to experiment; and as a ready access to a sufficient quantity of the medium is necessary for this purpose, all scientific men have consented to select air as the most appropriate subject of investigation. The science has in consequence been called Pneumatics, and in nearly all elementary works we find an account of the chemical constitution of the air, the extent of the atmosphere, and other facts which do not strictly belong to the science, and yet may be introduced with great propriety.

THE EXISTENCE OF AIR.

The existence of an atmosphere surrounding the earth is proved by many circumstances. An enquiring man, without drawing his knowledge of the existence of air as a fluid surrounding the earth, either from books or the information

obtained by the investigations of scientific men, could not fail to be acquainted with the fact. Although it may, in one sense, be said to be invisible, yet the blue colour of the celestial vault can only arise from the presence of atmospheric air. The air, like sea water, is colourless in small quantities, but in large masses reflects sufficient colour to affect the eye. The presence of this colour may therefore be considered as a proof of the existence of an atmosphere.

But we have a stronger proof than this, in the fact that we are every where existing in a space which constantly exhibits the property of inertia. When moving from one place to another we frequently experience resistance, and bodies in motion are evidently acted upon in the same manner. At other times we feel, when at rest, an invisible force operating upon us. These effects can only be accounted for by admitting that the earth is surrounded by an elastic fluid, and in nearly all cases we may discover the origin of the effects produced, whether they arise from the motion of the medium, or the resistance it offers to bodies passing through it.

We need not, however, multiply proofs of the existence of an atmosphere, for all persons will be willing to admit the fact; and should any of our readers desire a more extensive evidence, it will be found in the properties which distinguish it, and of which we are now about to speak.

AIR HAS WEIGHT.

It is difficult to imagine what idea some of the ancient philosophers can have had of the properties of atmospheric

air; for even those who admitted it to have weight, imagined that weight to be of a character somewhat different from the weight of other substances. Aristotle says, all the elements except fire have weight; for a bladder weighs more when inflated with air than when it is empty, yet some of the historians who profess to describe his opinions, assert that he maintained air to have a weight between fire and earth.

There are many effects constantly observed by every one, and several popular experiments, which will illustrate the weight of air and the pressure of the atmosphere. In describing the latter, we shall have frequent occasion to refer to the air pump, an instrument used to withdraw the atmosphere from any given space. This instrument is described in another part of the present chapter, and those who are unacquainted with its use and construction, may peruse what has been there said before they read further.

When two smooth plane surfaces are brought into contact, they will closely cohere. This cohesion is in a great measure due to the pressure of the atmosphere, but as it is much stronger between some substances than others, cannot be entirely attributed to the atmosphere. In all cases, however, it will exert a pressure of about fifteen pounds upon every square inch. In grinding glass, it is said, the glass and the tool, when the smooth surface has been almost obtained, adhere so closely together, as to require more than the force of a man to separate them.

We may also observe the influence of atmospheric pressure, if we expel the air from a pair of bellows, and, shutting

the nozzle and valve hole, attempt to separate the boards. A considerable force will be required, for the pressure of the atmosphere is acting upon their outer surfaces without any counterbalancing force within. But if the nozzle be unstopped, and the air be admitted between the boards, they will easily be drawn apart, for the external pressure will then be neutralized by the expansion of the air within.

If a tumbler be filled with water, and covered with a piece of thin wet leather, fastened to some immoveable body, it will hardly be possible to separate them by pulling the glass upwards. This is evidently to be attributed to the external pressure of the atmosphere, and explains the cause of that strong adhesion of limpets, perriwinkles, and other univalve fish to the rocks on which they fix themselves. The edge of the shell fits tightly upon the rock, and by a muscular action, the animal is able to produce vacuum within, so that the pressure is altogether on the exterior. Flies and some other insects also are able to walk over a ceiling for the same reason. A peculiar sort of lizard, an inhabitant of Java, called the Gecko, is supported when walking upon a perpendicular wall, and even upon a flat surface with its legs upwards, by the atmospheric pressure, for it is capable, as proved by Sir E. Home, of producing a vacuum beneath the feet, causing an unresisted pressure of fifteen pounds upon every inch of the body. It is to this atmospheric pressure that we must attribute the extreme difficulty of separating the shells of an oyster, erroneously ascribed to the muscular power of the animal, for if an aperture be made in the shells, they may be easily opened. Many of our readers have per-

haps amused themselves in boyhood, in raising stones of considerable weight by circular pieces of wet leather fastened to a string: the close adhesion in this as in other instances which have been mentioned is to be attributed to external atmospheric pressure.

The pressure of which we have been speaking is exerted in every direction, not merely downwards, but also upwards and sideways. Many instances of this might be also mentioned; one or two will be sufficient. If a hole be made in a cask filled with water, or any other liquid, no stream will issue from it, because the pressure of the air resists the internal pressure of the liquid; but if another opening be made, the liquid will then be discharged. It is upon this principle that some ink stands are formed. A very ingenious, and probably accurate, explanation of the decrease of water in springs during a frost, may with propriety be mentioned in this place. It is commonly supposed that the water in the interior of the earth is frozen, but this cannot possibly be the case, and the real cause may perhaps be found in the exclusion of the atmospheric air, by the consolidation of the superficial crust of the earth, from the reservoir.

We may now proceed to describe some experiments illustrating the weight and pressure of the atmosphere. To prove that air has weight, take a large copper or glass bottle fitted with a stop-cock. Screw the bottle to the plate of the air pump, and after exhausting the air, turn the cock. Suspend the bottle to one end of an accurate balance, and counterpoise it with sufficient weights. When this has been

done, admit the air again, and it will be found that the arm of the balance to which the bottle is attached, will preponderate. Many experiments have been made to determine the weight or specific gravity of atmospheric air. Ricciolus estimates it compared with water as 1 to 1000; Meisenne as 1 to 1300; Lana as 1 to 640; Galileo as 1 to 400; Boyle as 1 to 1000; but we can best depend upon the results of Sir George Thuckburgh, who found the ratio to be as 1 to 836.

To prove the downward pressure of the atmosphere, we may adopt either of the following experiments:—

1. Take a small glass receiver, open at both ends, one being ground to fit the plate of an air pump accurately, and the other closed by a piece of bladder tied over it; place this upon the air pump, and proceed to exhaust the air it contains. The downward pressure of the air will soon be observed causing a strain upon the bladder which will burst as soon as the counteracting force within is removed. A flat piece of window glass may be broken in the same manner.

2. Place a receiver, having a small hole at the top, upon the plate of a pump, and covering the opening with the palm of the hand, proceed to exhaust the air. A considerable pressure will immediately be felt upon the back of the hand which increases as the exhaustion proceeds, and the hand will be so firmly pressed to the receiver, that it can scarcely be removed without readmitting the air.

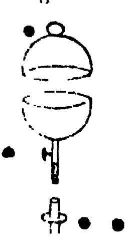
3. There is an interesting experiment which may be employed either to prove the porosity of vegetable substances,

or the pressure of the atmosphere. If a cup formed of willow, or any other porous wood, be attached to a brass plate so as to close the aperture of an open receiver, mercury may be made to pass through it when the internal air is removed by the action of the air pump. It will be necessary to caution the student that great care must be taken in performing this experiment, for if the mercury should enter the pump, it will amalgamate with the metal and seriously injure the action of the instrument.

But the pressure of the air is upwards as well as downwards, a fact which may be easily proved. Fill a wine glass or tumbler with water, and place on its surface a piece of cardboard; invert the vessel so that its mouth may be downwards, and the card will remain suspended by the pressure of the air, although it is bearing the whole weight of the water.

To prove that the pressure is in every direction, we must use an apparatus called the Magdeburg hemispheres, fig. 16. Two hemispherical cups are so formed in brass or any other hard metal, that when placed together they may fit air-tight. To one of these a handle is attached, and to the other a screw fitting the air pump. A small hole is made in the centre of the screw, forming a connexion between the air pump and the interior of the closed hemispheres. To use the instrument, attach one hemisphere to the plate of the pump, and let the other be fixed firmly upon it. Exhaust the air, and the two cups which might have been before sepa-

Fig. 16.



rated by a child, will require the force of two strong men to pull them asunder. The force required to separate the hemispheres will depend upon their diameter and the degree of exhaustion. Supposing the diameter to be four inches, the area of the section will be

$$4 \times \cdot 7854 = 12 \cdot 5664 \text{ inches,}$$

and if the pressure be 15lbs. on the square inch, a force will be required to separate them equal to

$$12 \cdot 5664 \times 15 = 188\text{lbs.}$$

Many fountains and springs of water may be attributed to the pressure of the atmosphere. In some countries vast columns of water are ejected from beneath the surface of the earth to a considerable height; the Geyser of Iceland is an example. We do not mean to assert that it is produced by this cause, but it is an effect similar to that which would be produced by atmospheric pressure. To show how atmospheric pressure may act in the ejection of a vertical column of water, we may introduce an experiment easily performed by any of our readers who are in possession of an air pump. Opticians are accustomed to make a plate with a stop cock attached to its tube for receivers, which may be screwed on at pleasure to the air pump. If a long receiver be placed on one of these, and the contained air be exhausted, the whole of the apparatus may be removed from the air pump, and a beautiful jet exhibited. Plunge the lower end of the tube into an open vessel containing water, and immediately the stop cock is turned, the water will rush through the aperture and ascend to the top of the receiver, forming an artificial fountain. This effect is due to the external pres-

sure of the atmosphere acting upon the surface of the water contained in the vessel. As there is no resisting force in the interior of the receiver, the water must, according to the one principle of equilibrium, already explained, be forced upwards in a perpendicular direction.

The influence of atmospheric pressure is so important, that we may speak of it as a principle which unites and gives stability to the whole framework of nature. Things animate and inanimate are alike indebted to it for the continuance of their forms, constitutions, and even being. Many of the substances which present to us the appearance of solids and liquids would be, without its controlling influence, floating in space, as attenuated and almost imperceptible vapours. To imagine a world without an atmosphere, and a temperature approaching to that of the tropics, must bring to our imagination a sterility, which even those who have crossed the Arabian deserts cannot possibly conceive. Without the external pressure of the atmosphere, the most genial influence of the sun would produce a vaporisation, which in a few months would exhaust our rivers and oceans, and make the most luxuriant and fertile spot a wilderness. If we connect with this picture of desolation the entire absence of light, or we should rather say, its happy existence under any of the circumstances with which we are acquainted with it, we shall have some, but an imperfect idea of the importance of the terrestrial atmosphere, so far as relates to the influence of its pressure. We may imagine creatures living without air, but it is scarcely possible to imagine any form of organised life, constructed with vessels, and fluids moving in

them, without an external force capable of resisting their expansive powers. If our own atmosphere were removed, the sources of animal life would instantly become the agents of death.

The vessels and their fluids might still continue parts of the animal system, but their mysterious revolutions would be instantly destroyed by their own energy, and the canals which are now the reservoirs of life and activity would be at once incapacitated for the conveyance of those streams which it is now their duty to transmit, from one portion of the body to the other. The blood-vessels of men and animals, would burst, if the external pressure were removed, and the juices of plants would exude through their thick but porous coatings. Life in fact would be instantly extinct upon the surface of this earth, if the atmosphere were withdrawn, even although it were possible for animals to exist without oxygen, and plants without nitrogen.

The wisdom and benevolence of the Deity, is not in any case more strikingly displayed than in the provision of a force capable of neutralizing the destructive powers which exist within us. We may learn from all the conditions of nature, and from none more than that we have been considering, that we are the especial objects of his solicitude, and that every law of nature has been established with a view to our support, happiness, and gratitude. And although there are higher motives as incentives to our love, yet we may draw, actuated by the principles of revealed religion, from external nature motives to obedience and adoration. It was in His power simply by the increase or decrease of pressure to have made

the present state of existence as miserable to man as the representations of the future to those who reject counsel and despise reproof. Every law of nature has for its ulterior object, the happiness of man.

THE HOUSEHOLD PUMP AND BAROMETER.

The effects which we now know to be produced by the pressure of the atmosphere, were formerly attributed to nature's abhorrence of a vacuum. By this dogma the philosophers before the time of Galileo were accustomed to account for the action of the pump in drawing water. The air contained in the cylinder, they said, was exhausted by suction in the process of raising the piston, and as there could not be a vacuum, the water rushed in and occupied its place. It was however accidentally discovered by Galileo, that water could not be raised in a pump when the piston was more than 33 or 34 feet above the surface of the water.

The shortest and least troublesome method of explaining this phenomenon was, to state that nature did not abhor a vacuum to a greater height than 34 feet. This explanation, if such it can be called, satisfied many persons who esteemed themselves philosophers. Galileo entertained a doubt of the truth of the dogma, and attributed the elevation of the water to an attraction between the piston and the fluid. To account for the fact that water could not be raised to a height of more than 34 feet, he stated that the weight then overcame the attraction of the piston.

Torricelli, who had been Galileo's pupil. was not satisfied with this explanation, and commenced an investigation of the phenomena. After performing a series of interesting experiments, he was led to the conclusion that water could not rise in an exhausted tube to a greater height than thirty-four feet, because it then exactly counterpoised the pressure of a column of atmospheric air, having a base of the same dimension. It then occurred to him that the same force ought to support a column of mercury; but as mercury is about four times heavier than water, its height should not exceed 29 or 30 inches. The result was as he expected, and his hypothesis was confirmed; but he is said to have regretted that the discovery had not been made by Galileo, whom he greatly respected, and considered to have almost a claim to the discovery. Valerianus Magnus published the experiments of Torricelli at Warsaw as his own, with an impudence seldom practised even by pretenders to philosophical discoveries. His claims to the honour have, however, been supported by some writers.

The conclusive experiments to which we have referred, may be easily repeated by the reader.

Take a glass tube, having one end hermetically sealed, and, filling it with mercury, place the open end in a cup containing the same metal, and be careful that no air shall enter the tube. It will be found, that the mercury will be suspended in the tube to the height of about thirty inches from the surface of the metal in the cup, and will there remain stationary. In this position the mercury in the tube exerts exactly the same pressure upon that in the cup, as the

atmosphere itself. It is, therefore, evident, that by determining the pressure of the mercury upon a base of any extent, we shall discover the pressure of the atmosphere. In this way it has been proved that the atmosphere has a pressure of about fifteen pounds upon every square inch.

The principle of the household or lifting pump, may be further illustrated by an allusion to fig. 17 : W, represents the well from which the water is to be drawn : *v*, is a valve at the end of the cylinder opening upwards : and A, is a valve in the piston, also opening upwards. Both these fit their openings closely when the pump is at rest, but are easily moved by a pressure from below.

Fig. 17.

To explain the process by which the pump has the power of raising water, let us imagine the piston to be brought to the bottom of the cylinder. As the piston is drawn up, a vacuum is left in the cylinder beneath, for the air cannot rush in, as the valve A opens only upwards. But the usual pressure is exerted on the surface of the water, and as there is no air in the cylinder to oppose it, the water rises, and occupies the place from which the air has been excluded. When the piston is forced downwards, the lower valve *v*, is closed, and the resistance of the water opens the upper valve A, through which it of course rushes. When the piston is again elevated, the water is drawn upwards, and makes its escape through the spout. As the pressure of a column of water about thirty-four feet high, is equal to the pressure of an atmospheric column of

the same base, water cannot be ever raised to a greater height.

This ingenious experiment did not gain for Torricelli an immediate reception of his theory. There were many philosophers in Europe, who still preferred the supposed principle *fuga vacui*. The young Pascal, however, became its defender, and at the age of twenty-three published his clever work "Expériences Nouvelles touchant le Vuide." To him also we are indebted for the suggestion of an experiment that confirmed the opinions of Torricelli. Having proved that when the air was removed from the surface of the mercury in the cup, the column fell, he induced M. Perrier, his brother-in-law to ascend the Puy de Dôme, a mountain in Auvergne, in order to ascertain the effect produced by bringing it into situations where it would have a less column of the atmosphere to support. The result was as he anticipated; the column of mercury decreased in height just in proportion to the elevation to which it was carried. This may be considered as the first barometer that was ever made.

The barometer is an instrument used to determine the changes produced in the pressure of the atmosphere by heat or other causes. If we take a glass tube about three or four and thirty inches in length, and, filling it with mercury, invert it into a cup containing the same fluid, the mercury will begin to fall as soon as the finger is removed from the open end, and oscillate up and down several times, at last fixing itself at a height of between twenty-eight and thirty inches. This curious effect can be accounted for only in one way, and that is, by supposing the column of mercury to counterbalance

the pressure of an atmospheric column; for according to the fundamental principle of fluids, that any volume will have an uniform level, the mercury ought, it may be supposed, to flow out of the tube into the vessel. Although this is not the result, the law referred to is not in any degree invaded. The tube is first filled with mercury, and then plunged into a reservoir of the same liquid. There are then two forces acting upon the surface; one is the pressure of the atmosphere, and the other the pressure of the mercurial column. When these two are exactly equal, rest must be the result. The mercury could not fall in the tube unless one of the first laws of nature was destroyed. It has been proved that matter is inert and governed by forces, and consequently when two equal forces are acting upon any substance, and in contrary directions, rest must be the effect. It is thus that the mercury is supported in the tube.

From a variety of observations made upon the barometer, it is found that the length of the column varies according to the condition of the atmosphere. In this country it has stood as low as twenty-eight inches, and as high as thirty-one. This has happened at the level of the sea. If it be carried to a greater height, the column will always become shorter, for the mercury has then a shorter column of the atmosphere to support, and also one whose density becomes rapidly less and less.

It is supposed by some persons, that the changes in the atmosphere may be predicted by the barometer, and to some degree they may. The alteration of weight is clearly indicated by the fall and rise of the barometer; but it does not

explain the cause from which that alteration proceeds. Meteorologists are very imperfectly acquainted with the causes, directions, and influences of the contending currents frequently produced in the atmosphere. There are general rules by which an experienced observer may gather some information from the rise or fall of the mercury, but the system usually adopted is hardly less than childish.

Barometers are also used to determine the height of mountains and other elevations, above the surface of the earth. As there is a relation between the height of a column of mercury, and the column of atmospheric air which supports it, there must evidently be a means of measuring an elevation by the barometer. Many attempts have been made to reduce the methods usually adopted to a system; but difficulties presented themselves, which were not at first perceived. We may now, however, apply this method of measurement with great facility, and obtain results which have a claim to accuracy.

ELASTICITY OF AIR.

Elasticity is one of the most striking properties of atmospheric air. If we take a syringe to the end of which a solid piece of metal is attached, the piston, being air tight, may be forced downwards to a considerable distance. The air, therefore, in the tube or syringe, suffers compression; but as soon as the pressure on the piston is removed, the air recovers its former volume, and the piston is driven back

into its first position: air is, therefore, possessed of elasticity. So also, if the piston be nearly at the bottom of the tube, and be drawn up to the top, the air, which may at first have only occupied the space of one inch may be made to fill the whole of the tube.

From these two experiments we discover that air has various densities according to the circumstances under which it is placed. In the instance of condensation its density was great, in that of rarefaction was small. Now precisely the same thing holds good with respect to the atmosphere. The density of the atmosphere at any particular height is just in proportion to the superincumbent mass of air. Although air is so very elastic, it suffers considerable condensation in the lower regions of the atmosphere where it bears much pressure; and it extends itself as much in the higher regions where there is no force to neutralize its elasticity. The stratum of air immediately in contact with the surface of the earth is more dense than any above it, because it sustains a greater pressure, and its particles are consequently brought into closer contact. Every step therefore as we ascend from the general level of the earth, the air becomes less dense because it sustains a less pressure, and its particles are not so close to each other.

The great law of the elasticity of the air is, that it increases proportionally with the density. The air exerts, as we have already shown, a pressure of fifteen pounds upon every square inch at the surface of the earth, that is the lowest stratum of air is confined in its present bulk, or has

its present density by a pressure of fifteen pounds upon every square inch. If that pressure were removed, then its elasticity would cause it to expand and fill a much larger space. But if we would give it a double density, that is, reduce its bulk to one half, then a pressure of thirty pounds must be exerted on every square inch, and if a triple density be required, a triple pressure must be exerted, because its elasticity would be increased in the same proportion. This is what is meant by the expression, that the elasticity of the air increases proportionally with the density.

Let us for illustration imagine that we are placed in a situation where there is no atmosphere; in order to keep a portion of air at the same density as that on the surface of the earth, we must confine it with a pressure of fifteen pounds on every square inch, at a double density with a pressure of thirty pounds, and so on, for its elasticity increases with the density.

We do not, however, know to what extent the rarefication of air may be extended by the removal of pressure, but the particles will continue to separate until their gravity just balances their mutual repulsion. The extreme elasticity of the air, when the pressure is relieved, may be seen in a simple experiment.

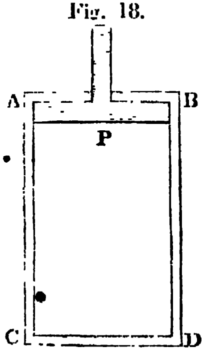
Take a bladder containing a small quantity of air, and placing a weight of nearly fifteen pounds upon it, let it be put under the receiver of an air pump, and the air in the receiver be exhausted. As the process goes on, the bladder will be more and more inflated, and at last raise the weight,

showing that the expansion increases with the diminution of pressure. Another experiment of a different kind may be made to illustrate the same fact.

Take a bulb containing coloured water, the upper part having a little air, and place the stem in a glass containing the same fluid. Put the whole apparatus under a receiver and exhaust it; the pressure of the air being removed, its elasticity causes it to expand, and to fill the whole of the bulb, forcing the liquid into the glass vessel.

To illustrate the law still more clearly, that the elasticity is in proportion to the density, another experiment may be made.

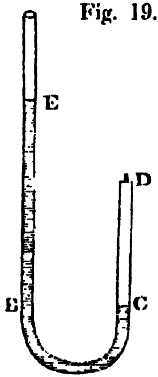
Fig. 18.



Let A, B, C, D fig. 18: be the section of a cylinder one inch square, and P a piston moving in it air tight. Now let the pressure upon the piston be equal to fifteen pounds, then it is clear that the elastic force is equal to the same, or the piston would not remain in its position. The piston may then be loaded with a fifteen pound weight, and the pressure exerted upon it will be equal to thirty pound. The elastic force is not equal to this, and the piston will sink, to half the depth of the cylinder. Its elastic force, therefore, must be twice as great in the present situation of the piston as it was at first, and the air is compressed into half the space. Hence it will appear, that the elasticity increases proportionally with the density.

Again, let A, B, C, D, fig. 19, be a bent tube, and

Fig. 19.



let the short leg have a stopcock attached at D. The stopcock being open pour in the mercury to the height BC. Now, according to the law of hydrostatic pressure, the surface of the mercury in the two arms will be level. While the stopcock is open, the pressure of the atmosphere upon both these surfaces is equal, but close the stopcock, and you entirely remove the pressure upon the leg BC. But the elasticity of the enclosed air is equal to the pressure of the atmosphere, or it would not have had that particular density. The level of the mercury will therefore remain the same in both arms of the syphon.

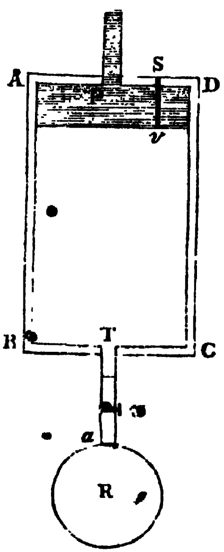
The tube BB may now be filled with mercury to the height of thirty inches, which exerts a pressure equal to that of the atmosphere, and the following conditions will be obtained. The surface B is sustaining a pressure equal to thirty pounds, one half produced by the atmosphere, and the other by the superincumbent mercury. There is on the other hand only a force equal to fifteen pounds on the surface C, arising from the elasticity of the enclosed air. In consequence the air suffers compression until it has acquired an elastic force sufficient to balance the increased pressure, which it will have when reduced into half its former bulk.

It must not, however, be forgotten that there is another law by which the elastic force of air is governed—it increases with the temperature, although the density is diminished. This law may be shown approximately by a simple experiment: take a

flaccid bladder, and immerse it in hot water; the bladder will be gradually inflated by reason of the increased elasticity of the air, though the density is evidently greatly diminished.

Before we proceed further in our investigation of the properties of air, it will be necessary to describe the construction of those instruments employed for its condensation and rarefication. An increased density or rarefaction must often be given to the air contained in some particular vessel, and the mechanical contrivances employed are constructed upon the known principles or laws of elastic fluids. Without an apparatus by which any particular state of the fluid may be obtained, it would be impossible to conduct a course of practical enquiries.

Fig. 20.



In order to condense air, that is, to force into any space a larger quantity than it contains when the fluid has a free communication with the atmosphère, we employ an instrument, called the condensing syringe, the construction of which will be understood by reference to fig. 20.

Let A, B, C, D, fig. 20, be a cylinder, with a tube T attached: P is a piston moving air tight in the cylinder, and having an aperture *sv* to the under surface of which a valve opening downward is affixed: *u* is a stopcock to the tube T, and to the end of the tube a valve is attached opening downwards. R is

a receiver, and it is required to condense a certain quantity of air into it.

Let us imagine the stopcock to be open, and the piston to be at the top of the cylinder. There is now within the cylinder a quantity of air, having the same density as the atmosphere. Press the piston downwards, and as it passes along it will compress the air before it, and as its elastic force increases with its density, the valve will be opened, and the air will rush into the receiver. The valve is then closed by the superior force of the interior air, which tends to force it outwards. As the piston is drawn up from the bottom it leaves a vacuum, and the valve *v*, having no force below to support it, is opened by the pressure of the external air and the cylinder is again filled. The same process may be repeated until so much air has been forced into the receiver, that the elastic force of that condensed by the piston in the cylinder shall be unable to open the valve in the tube.

Sometimes a number of these syringes are connected, and made to communicate by tubes with a single receiver. All these syringes are so arranged that they may be worked at the same time, and by the same motion. Such an instrument is called a condenser, and by its use we obtain a great multiplication of power, but it is necessary that the receiver employed should be exceedingly strong, to resist the elastic force of the internal air.

The air gun is an application of the instrument just described. It is formed like the common gun, except that it is without a lock, and is provided in its stead with a con-

densing syringe and air chamber. The object of a gun is to propel with great velocity a ball or shot. In the common gun, and also in cannon, this is done by the expansive force of the elastic fluid or gas, which is formed by the explosion of gunpowder. In the air gun the principle is precisely the same. By the syringe a large quantity of air is condensed into the air chamber, and the shot or ball is placed in the tube. The gun is then charged. When the condensed air is allowed to escape, it instantly begins to expand itself, and with so much violence, that it propels the ball, or whatever may be in its progress, with great velocity. Under some circumstances, this is a most valuable instrument; but in others most dangerous. Such is the character of man, that all the most valuable improvements of science may be made the means of putting in force evil intentions. In a lawless state of society, the air gun might become a powerful assistant in supporting rapine and bloodshed.

A passing allusion has been made to the fact, that gaseous bodies may be forced into a liquid state by condensation. A few more particular remarks on this subject are, we think, necessary. There is much probability that the gases are the vapours of liquids so volatile, that their boiling point, under natural atmospheric pressure, is lower than the lowest temperature which can be obtained by art.

Atmospheric air, for instance, maintains its gaseous form, not only at the poles, but at heights far beyond the research of man; and it does so, because the cold is not sufficient to reduce the gases of which it is composed into their liquid state.

There seemed but one way by which to determine whether

gaseous substances could be compelled to take the form of liquids; and that was by subjecting them to so great a pressure as to neutralize their elasticity, which we have already shown to increase in proportion to the density. Mr. Faraday accomplished the liquefaction of many of the gases by subjecting them to the pressure of their own atmospheres. The substances from which the gas is to be formed, are placed in a strong tube hermetically sealed and slightly bent in the middle. The gas is then generated, and the pressure in some instances becomes sufficient to condense it into a liquid, which falls to the cool end of the tube. Immediately the pressure is removed, the substance resumes its gaseous or elastic state.

All the gases have not yet been liquefied, and those which have suffered condensation, require extremely variable pressures. The following is a table of the results obtained by Mr. Faraday:—

Sulphureous acid gas	2 atmospheres at	45° F.
Sulphuretted hydrogen gas	17	50° F.
Carbonic acid gas	36	32° F.
Chlorine gas	4	60° F.
Nitrous oxide gas	50	45° F.
Cyanogen gas	3·6	50° F.
Ammoniacal gas	6·5	50° F.
Muriatic acid gas	40	50° F.

We must now endeavour to describe the means by which the atmospheric air, contained in any vessel, may be rarefied; and for this purpose two instruments have been invented—the exhausting syringe, and the air pump.

Fig. 21.

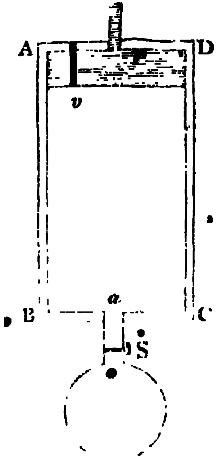
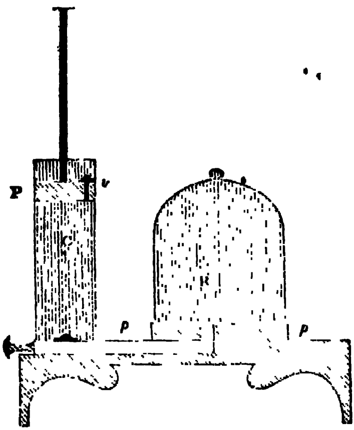


Fig. 21 will enable us to explain the construction of the exhausting syringe. Let A, B, C, D be a cylinder with a tube and a stopcock attached, and P a piston moving in the cylinder, air tight, with a valve *v* opening upwards. At the bottom of the cylinder there is a valve *a*, which consists of a piece of oiled silk impervious to air, but stretched over the aperture so loosely that a small pressure from below will be sufficient to raise it, and admit the air to rush out from the receiver. Let the receiver be attached, the stopcock open, and the piston at the top of the cylinder. The cylinder and receiver are now filled with air of the usual density as found on the surface of the earth. Press down the piston, and the air in the cylinder being compressed, increases in elastic force, opens the valve *v*, and allows the air to escape, so that the piston reaches the bottom and the valve is closed. It is drawn upwards, and a vacuum exists in the cylinder, for the valve *v* prevents the access of air. But as there is no pressure above upon the valve *a*, it is opened by the elastic power of the air contained in the receiver, and a part of the fluid escapes into the cylinder. When the piston is forced down again, the lower valve is closed, and the upper one is re-opened as soon as the elastic force of the contained air has sufficient power. This process may be continued until the air contained in the receiver has not power to open the valve.

The air pump is but a modification of the exhausting syringe. It is constructed in various ways, but its principle in every instance is the same. Its general action may be described by reference to fig. 22, which is a sectional view of its construction. Let R be a receiver for exhaustion, resting upon a smooth and evenly ground plate *p p*. The receiver and cylinder *c* are connected by a tube, and the aperture at the cylinder end is covered by a piece of silk, easily moved upwards, which acts as a valve. P is a piston working air tight in the cylinder, *v* a valve in it opening outwards.

Fig. 22.



The principle of action in this machine is very simple. Let us suppose the piston to be at the bottom of the cylinder. Of course there is no air between the bottom of the piston, and the bottom of the cylinder. The piston is now drawn up and a vacuum is left. The pressure of the atmosphere is removed from the top of the cylinder valve, and the elasticity of the inclosed air in consequence opens it, and a portion of that contained in the receiver and connecting tube rushes into the cylinder *c*. Immediately the piston begins to descend, the density of the air in the cylinder is increased, and the cylinder valve is closed: when

the elastic force of the air in the cylinder is greater than the pressure of the exterior air, the valve is raised, and the air rushes out. A vacuum is then again produced, a part of the air still remaining in the receiver enters the cylinder, and the same circumstances happen as often as the piston is raised.

The air contained in a receiver connected with the air pump can never be entirely exhausted. It will become more and more rarified by every stroke of the piston, but a vacuum can never be obtained.

Let us suppose the cylinder to contain one-fourth the amount of air in the receiver, tube, and cylinder together. A fourth part of the whole must be expelled by every stroke of the piston. The following table will show the quantity of air thrown out, and the quantity remaining after seven successive strokes.

No. of strokes.	Air expelled.	Air remaining.
1	$\frac{1}{4}$	$\frac{3}{4}$
2	$\frac{1}{4}$ of $\frac{3}{4}=\frac{3}{16}$	$\frac{9}{16}$
3	$\frac{1}{4}$ of $\frac{9}{16}=\frac{9}{64}$	$\frac{27}{64}$
4	$\frac{1}{4}$ of $\frac{27}{64}=\frac{27}{256}$	$\frac{81}{256}$
5	$\frac{1}{4}$ of $\frac{81}{256}=\frac{81}{1024}$	$\frac{243}{1024}$
6	$\frac{1}{4}$ of $\frac{243}{1024}=\frac{243}{4096}$	$\frac{729}{4096}$
7	$\frac{1}{4}$ of $\frac{729}{4096}=\frac{729}{16374}$	$\frac{2177}{16374}$

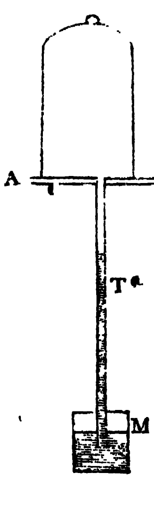
After seven strokes, therefore, only $\frac{2177}{16374}$ parts of the air first contained in the receiver will remain. By continuing the process the air may be still more rarefied, but it is evident that a perfect vacuum can never be produced, as in every instance we only take a part of the remainder.

The formation of aqueous vapour in the receiver during rarefaction, will also prevent us from ever producing a perfect vacuum. It is stated by Mr. Cavendish that water is turned into vapour at the temperature of 72° F., when the pressure is not more than $\frac{1}{40}$ of the atmospheric pressure, that is, when the pressure of the air cannot sustain more than three-fourths of an inch of mercury. Now in every pump, to whatever degree of artificial dryness it may be brought, there must be some moisture adhering, which will turn to vapour when the exhaustion arrives at a certain point, that is a degree proportional to its temperature.

The property of the rise and fall of liquids in tubes, may be conveniently used to determine the degree of rarefaction in the receiver of an air pump.

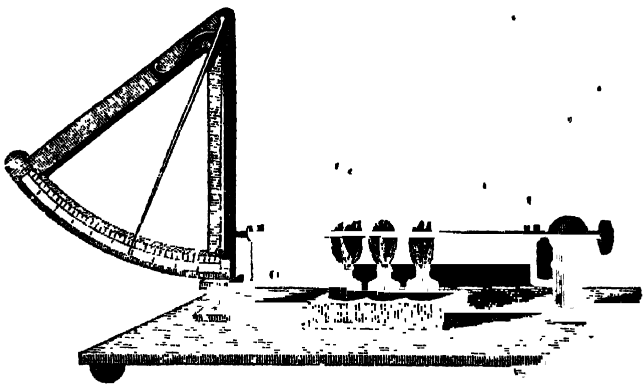
That in which mercury is made to rise is the most frequently used. Let A B, fig. 23, be the plate of an air pump, and T a tube open at both ends; one is inserted into the plate, and the other drops into a vessel M, containing mercury. Before the process of exhaustion commences the pressure on both ends is the same, but the tube being connected with the receiver will suffer exhaustion in the same degree as the receiver itself. As the air is exhausted from the tube, the mercury must rise, because the internal air cannot any longer sustain the pressure of the external air upon the mercury. The column of mercury contained

Fig. 23.



in the tube will, therefore, be the measure of the rarefaction.

There are many other subjects of inquiry to which we might direct the attention of the reader, and forming part of the science of pneumatics. It is, however, our object to present the elements of science, and to select those facts which may be considered the foundation of future acquirements. We cannot, therefore, enter more minutely into the investigation of this subject, and especially as we shall have to devote a large space to Electricity, which is now forming a prominent enquiry among all scientific men.



THE PYROMETER.

CHAPTER IV.

HEAT.

In the investigations we have as yet entered into, our attention has been confined to the laws which regulate matter under its three conditions of solids, liquids, and gases. But we have had occasion to refer to agents which have an influence upon substances in producing and regulating these conditions. These agents have been very improperly termed imponderable substances. Of all the properties possessed by bodies, weight is by far the most universal. We can have no idea of matter without weight, and so commonly is this opinion received, that most persons are accustomed to distinguish spiritual from material existence by supposing

the former destitute of the property. An attempt has been made, in a former part of this work, to demonstrate that there is an attractive influence exerted on all bodies by each other, and that weight is the necessary result of this universal force. Not only is the earth attracted by the sun and the planetary bodies, but also by every feather which floats in the atmosphere, and in an equal proportion according to its mass and distance. When, therefore, we use the expression imponderable body, we imply the destitution of a property in material existence, without which matter cannot possibly exist. The particles which compose substances are united together by a cohesive force, supposed to be regulated by one of the so called imponderable agents. But could we suppose an individual atom to exist in space, and as far distant from any combination of atoms as the furthest fixed star is from the earth, the property of attraction would still be in existence though its influence might not be perceptible. But let one other particle be united with this, and their distances from each other and condition would instantly be under the control of heat, electricity, and other agents. We shall not at present attempt to determine the nature of those forces called heat, electricity, and magnetism, but from the remarks which have already been made, it must be quite evident, that we cannot adopt the same method of investigation, in discussing these sciences, as we have done in those which have before engaged our attention. We have hitherto been speaking of the manner in which substances are acted upon by forces, but we have now to consider some of the forces themselves, insensible frequently in their effects,

and yet having the whole frame of material existence under their control. To ascertain the nature of these forces is not at present within the reach of philosophical enquiry, but it will not be difficult to trace the effects which they produce. This we shall attempt to do, with as much perspicuity as the subject will admit, in the following pages.

THE DILATATION OF BODIES BY HEAT.

Of all the effects produced upon bodies by the increase of temperature, none are more striking than the enlargement of their volumes. We here use the word *temperature* to express an effect or operation resulting from heat. Were we to say the effect produced upon bodies by the increase of *heat*, we should justify the supposition that the alteration was occasioned by the admission of a larger quantity of heat. By temperature we mean the quantity of heat in reference to sensation. Heat is frequently communicated to bodies under such circumstances that it is inappreciable to the touch, a fact that will be explained in another part of this chapter. Thus when we say one body is hotter than another, the expression is synonymous with the assertion, that its temperature is greater. One illustration will at once convey to the mind of the reader the distinction we wish to draw between temperature and heat. Suppose we take two vessels, one holding half a pint of water and the other a gallon, and filling them from the same spring place them over a fire, they will both boil after exposure for a

short time, and if a thermometer be plunged into each, the same effect will be produced, that is to say, the mercury will be raised to exactly the same point. Now it cannot be supposed that the half pint of water has received as large a quantity of heat as the gallon, yet their temperatures are the same, both affecting the thermometer and even sensation equally.

Having explained the meaning attached to the word temperature, we may return to the assertion which called for these remarks, and endeavour to show, by a few popular experiments, that an increase of temperature produces in nearly all cases an enlargement of bodies.

THE DILATATION OF SOLIDS.

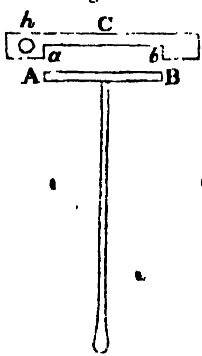
Those who have investigated the expansion of solid bodies from an increase of temperature, have found the subject surrounded with many difficulties. Of all solids metals suffer the greatest expansion, and of all metals lead is the most susceptible of this alteration of bulk. Yet the amount of dilatation suffered by this metal, between the extremes of temperature, is so small that it is very difficult to measure it. When a piece of lead at the freezing temperature is raised to that of boiling water, its expansion is only 350th part of its original dimensions. It must therefore be difficult to construct an instrument in such a manner, and with such accuracy, as shall enable us to determine so small an increase of bulk.

Experimentalists also experience another difficulty, arising

from the equal expansion of the body in every direction. If a bar of iron be raised in temperature it will expand in its breadth and thickness as well as in its length; and as substances must be presented under a variety of figure, it is almost impossible to have an instrument capable of determining the increase of volume. The instruments usually employed are therefore intended to measure the expansion in length only. They are called pyrometers, and although constructed in different ways are so arranged as to show upon a scale the amount of expansion at determined temperatures: one of the best of these is represented at the head of this chapter.

There are many ways in which we may illustrate the simple fact of the expansion of bodies by an increase of temperature. We will mention a few experiments and phenomena calculated to prove the universality of this result.

Fig. 25.



C, fig. 25, is a metallic plate with an aperture *a b*, of such a size that the brass cylinder, A B, shall exactly fit it when cold. To this cylinder is attached a handle of some substance that does not readily conduct heat. The end of the cylinder exactly fits into the opening when at the ordinary temperature. Allow the rod A B to remain for a time in boiling water, or let it be otherwise exposed to a high temperature, and it will no longer fit the notch in the plate, nor will the end of it pass through the hole *h*. Cool the bar by immersing it in cold water, and it

Fig. 26.

B.

will immediately suffer such a contraction as to enable it to pass into the two apertures formed to receive it.

Let B, fig. 26, be a ball which at common temperatures exactly fits into a tripod stand. Raise the temperature to a red heat, and it will no longer pass through the opening intended to receive it.

All the metals are peculiarly liable to this expansion when their temperatures are raised, and the most ingenious and valuable works of art are thus frequently disarranged. Some of the most accurate instruments of the astronomer suffer from even a slight change in atmospheric temperature, and watches and clocks lose or increase in time from the same cause. It is, however, the glory of science that in most cases it is able to discover a means of neutralizing the injury resulting from deranging causes, and in no branch of science is this more remarkably exhibited than in that under present consideration. When speaking of the pendulum it was stated that a pendulum beating seconds when at one temperature will not do so in another, in consequence of the expansion it suffers. Ingenious mechanics, however, have proposed methods by which such an error may be corrected —the gridiron and mercurial pendulums are arrangements of this kind.

It is not in the more refined operations of art alone that we can trace the influence of heat in the expansion of solids. In nearly all mechanical operations requiring the use of metals, the expansive power is made available to practical

purposes. The farrier places a hot shoe upon the hoof of the horse, that by its contraction it may adhere the tighter. The cooper binds his casks with hoops at a red heat for the same reason, and the plumber often has occasion to employ similar means for the accomplishment of his purposes. It has been already remarked that the same increase of temperature does not produce in all bodies the same amount of expansion, a fact that we need not attempt to prove, as the illustrations are exceedingly numerous in the most common operations of civilized life. There are however two important general laws, discovered by M. M. Lavoisier and Laplace, which we are compelled to notice.

1. The bulk of any body corresponds, at the same temperature, whether the process be that of heating or cooling. In proportion as we raise the temperature of a body from that of melting ice to that of boiling water, we occasion an increase of bulk, but whatever may be the amount of expansion for any increase of temperature, the same will be the amount of contraction for an equal diminution of temperature.

2. The metals and glass suffer an expansion, between the temperatures of melting ice and boiling water, proportional to that of mercury. But this expansion is not uniform; for if the same amount of increase in temperature be successively applied, the rate of dilatation will not necessarily be the same throughout.

DILATATION OF LIQUIDS.

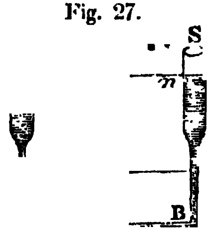
Liquids are subject to expansion from an increase of temperature, in the same manner as solids. The law of their dilatation differs from that of solids; and the effects produced upon them by heat may be more readily observed.

A very ready method of determining the expansion will at once suggest itself to the mind of the reader, but it is one which requires more accuracy than he may possibly think necessary. If we provide ourselves with a common thermometer tube, and graduate it accurately, the alteration of bulk produced upon any liquid it may contain, by an increase or diminution of temperature, may be easily observed. Thus for instance, suppose it is required to determine the expansion which any liquid undergoes at any or every step as its temperature is raised from 32 to 112 degrees of Farenheit's thermometer;—when the tube has been partly filled, the liquid must be first reduced to the temperature of 32 degrees by cooling mixtures, and the height of the liquid at that time carefully observed, plunge the bulb of the tube into some bath, the temperature of which may be conveniently raised to the height required, and the expansion of the enclosed liquid may be observed for every successive increase of temperature. If then the expansion of the tube be estimated, the change of bulk in the liquid will be determined. In performing this experiment great care must be taken that no portion of air be contained in the liquid, for as gases are subject to a more rapid expansion than liquids, a fictitious result would be obtained. There is another error, of an oppo-

site character, which must be avoided in performing this experiment; for it would cause the apparent expansion to be less than the real. All liquids vapourize at common temperatures, but the higher the temperature the greater will be the quantity of vapour formed. Now it is quite evident that a decrease of bulk must result from this process of vapourization, and consequently the real amount of expansion will not be obtained. To avoid this source of error, and to perform the experiment in the best possible manner, the liquid contained in the bulb and tube should be subjected to a sufficient degree of heat to cause a rapid vapourization. When all the atmospheric air has been expelled, and the upper part of the tube has been completely filled with the vapour of the liquid, the opening of the tube should be hermetically sealed. When the liquid is cooled down, there will be a vacuum in that portion of the tube unoccupied by the fluid; and by immersing the bulb into baths of different temperatures, the tube itself may be accurately graduated, and the degree of expansion or contraction under all circumstances estimated.

Many other methods of determining the dilatation of liquids have been proposed and employed by philosophers; we shall only mention that invented by MM. Dulong and Petit, for making experiments upon the expansion of mercury. The apparatus they used is represented in fig. 27, and

Fig. 27.



depends upon the well-known hydrostatical principle, that the heights of two upright columns of liquid communicating by a horizontal tube are in inverse proportion to their densities. T A, S B, are two vertical tubes, connected by the horizontal tube A B, and fixed in a firm position, upon a wooden stand, which may be accurately adjusted at pleasure. If the tubes be filled to the level *n n* with mercury, the fluid in each will continue at the same height so long as each column has the same temperature; but if the temperature of one be greater than that of the other, it will dilate, and become bulk for bulk lighter, so that the short column will support the longer. Now the heights of these columns will be in inverse proportion to the specific gravity of the mercury; from which it will appear that the relative specific gravities may easily be determined, and the dilatation will be known.

Experiments have been made to obtain the expansion of many liquids, but the importance of water as the type of the class, and as a fluid equally important in philosophical investigations, and for common uses, has induced many chemists to examine the changes which it undergoes with especial care. From all their results we learn, that it is a remarkable exception to the general law of expansion. Nearly all other liquids contract uniformly as they are brought near the point of solidification; but as the temperature of water is lowered, the rate of its contraction decreases until it is brought to about 39° 2′ of Fahrenheit. At this point the contraction ceases, and no visible effect is produced upon the fluid while passing through several degrees of lower temperature; after this dilatation is observed, which continues at an increas-

ing rate until the water is frozen. It would therefore appear, and the statement is supported by the experiments of nearly all philosophers who have investigated the subject, that water has its greatest condensation at a temperature between thirty-nine and forty degrees.

From all that we know of the dilatation of liquids by heat, it appears that the greatest variation in the uniformity of their expansion is at those points of temperature where they approach the gaseous or solid state; at all other temperatures the amount of expansion is, in most cases, regular. This is a fact which might be anticipated by a casual reflection on the constitution of bodies. Considering solids as a class, it is evident that contraction increases with the decrease of temperature; and it therefore follows as a consequence, that their expansions or contractions must be exceedingly various. Gases, on the other hand, being incapable of any other state from an increase of temperature, and being at the same time unable to assume a liquid form by any diminution of temperature under ordinary pressures, we are led to expect, and find our anticipations proved by experiment, that their expansibility within all known limits of temperature, is perfectly uniform. Liquids, being placed between the two extremes, and in most cases subject to either a condensation into a solidified state, or an expansion into an aeriform condition, are liable to an extreme irregularity when they approach those points which are the limits of liquidity.

From what has been already stated, it may be gathered, that a liquid becomes lighter, bulk for bulk, as its temperature increases. The lowest stratum of any unequally heated

mass of fluid is always the heaviest; nor can we, upon any other supposition, account for the arrangement of a liquid having different temperatures, in strata. Expansion being the necessary consequence of an addition to the temperature, there must be a difference of density between the several parts of a fluid which has a variation of condition in this particular. We may take one simple illustration of this; and inquire, what is the condition of any mass of fluid which is exposed to a temperature greater than its own. So long as the liquid remains of the same temperature, the density throughout is equal; but when the heat begins to impart its influence, the lowest stratum first, on the principle of conduction, to be hereafter explained, receives the effect, and, suffering expansion, rises; while the colder, and consequently denser, portions sink. There is, therefore, in every unequally heated liquid a constant series of currents, one rising and the other sinking.

To prove that a liquid of low temperature has a greater density, and therefore a greater weight, than one that is comparatively hot, the following experiment will be sufficient:—Pour into a glass vessel a quantity of water, at or near the freezing temperature, and upon it the same liquid raised to the boiling point. If this experiment be performed carefully, the hot water will float upon the cold, and no degree of mixture will be evinced: so, if hot water be first poured into the vessel, cold may afterwards be added, and that which has the greater density will sink to the bottom.

As liquids become specifically lighter with an increase of temperature, it is evidently impossible to boil any fluid by

application of heat on the surface. The part immediately in contact with the source of heat, would receive an increase of temperature, and becoming specifically lighter, would of course remain in its position, without giving any other portion of the fluid an opportunity of a similar change. When heat is applied to the bottom of a vessel containing a liquid, the portions which receive an increase of temperature, immediately rise and give place to the colder particles, so that there are two currents, one ascending, and the other descending. This fact may be easily exhibited, for if any fine powder, of about the same specific gravity as water, be intermixed in that liquid, and heat be applied, the particles will be seen to rise and fall according to their specific gravity.

To exhibit generally the fact that liquids expand with an increase of temperature, take a glass bulb and tube, and placing so much of any liquid in it, that it may fill a portion of the tube, apply heat to the bulb, and the liquid column will almost immediately begin to rise. It may be here remarked, that those liquids are the most expansible which have the highest boiling points.

To show that an equal temperature does not produce in all liquids an equal degree of expansion, take three glass bulbs and tubes of the same size, and filling them to the same height plunge them into boiling water, and all the fluids will expand, but not in the same degree.

DILATATION OF GASES.

When speaking of the dilatation of solids, it was stated,

that they have a uniform expansion with the increase of temperature from 32 to 212 degrees. Liquids are much less regular in the amount of dilatation, and gases much more so, not only passing through a larger range of temperature, but also presenting a remarkable similarity in relation to each other.

In the year 1801, and at about the same time, Mr. Dalton and M. Gay Lussac commenced a series of experiments on the dilatation of atmospheric air, and were both led to the conclusion, that it has a regular increase of expansion, in reference to the mercurial thermometer, between the 32d and 212th degrees of temperature. They also discovered that all gases and vapours had the same amount of expansion between the same temperatures. There was some little difference in their estimates of the increase of bulk between these limits: Mr. Dalton said that one thousand solid inches of air at 32° temperature, increased to 1325, at the temperature of 212°; while M. Gay Lussac gives the increase as 1375. The latter result has been proved by subsequent experiments to be the most correct. Now if it be allowed that there is an increase of 375 parts in 1000, between the temperatures of melting ice and boiling water, that is, 180 degrees, and the expansion be uniform, the increase of volume for one degree may be calculated by a simple division.

There are many experiments which may be performed to prove the expansion of gases by heat. As it is our main object in this work to direct the attention of the reader to elementary principles, and especially to explain

such experiments as will illustrate them, we shall proceed to describe those by which the dilatation of gases is commonly proved.

Take a small bladder, and having pressed out of it nearly all the contained air, tie the mouth tightly, and expose it to some source of heat. It may be placed before the fire or plunged into boiling water. The air receiving an increase of temperature, expands; and after a short exposure the bladder will be fully inflated.

Take a small bulb and tube, and having nearly filled it with some liquid, plunge the open end into a vessel containing the same fluid. A small bubble of air will then be seen in the bulb, and if a spirit lamp be lighted, and placed beneath it, the gas will expand so much, that in a short time the whole of the liquid will be expelled. If the lamp be then removed, the air will be rapidly cooled, contraction will follow, and the liquid again rise into its former position.

The mongolfier, or fire balloon, is an instrument which acts upon the principle we have just explained, and is a practical illustration of the expansion of gases. A bag of tissue paper or some other light substance is formed of a convenient shape, and beneath the opening is placed a piece of sponge saturated with some inflammable liquid. When the liquid is ignited, the contained air is rarefied, and becoming specifically lighter than the surrounding atmosphere, consequently ascends.

THE THERMOMETER.

The thermometer is an instrument used for measuring

degrees of temperature. It was invented by Santorio, an Italian physician, and is of so much importance that but few series of experiments can be performed without its aid. As we have given a description of this instrument in our work on the Earth, it is not necessary that a long explanation of its construction and use should be introduced in this place.

In order that philosophers may understand each other's experiments, it is necessary that some fixed and certain standard of comparison should in all cases be adopted, and especially in those measurements which have a more or less influence upon all our investigations. Temperature is an element, which, in almost every philosophical calculation, must be taken into account, and therefore, although any fluid, whether a liquid or a gas, whose expansion at certain temperatures is known, would be in fact a thermometer; yet the promiscuous use of different substances would only cause confusion, without some determined scale. From what has been already said, it is evident that gases expand more equably than liquids, and on this account they are preferable for thermometers; but their use is attended with so many practical disadvantages, and especially that arising from the great increase of bulk, that liquids are almost universally preferred. Of all liquids mercury is for ordinary purposes the best, as its boiling and freezing points are at the greatest distance. There are some substances which boil at a higher temperature than mercury, and these may be employed in those investigations for which mercury is unsuited.

LATENT HEAT.

Although the expansion of bodies by the influence of heat is the most evident, it is not by any means the most important or general effect resulting from this agency. Allusion has been frequently made to the existence of matter in three different states, and in speaking of the expansion produced by heat, it was found necessary to describe the effects in the three different states of solids, liquids, and gases. The origin of these several conditions must now be considered, for they are all referrible to the action of heat upon the elementary particles, or molecules of matter.

Considering the experiments which have been made upon bodies, and reasoning from analogy, we may fairly come to the conclusion that every solid may be brought into the liquid state. It is true, that we have an exception to this rule, as in carbon, but it must at the same time be remembered that every new method of obtaining a more intense heat, has been the means of reducing some substance which had previously resisted every attempt to bring it into a liquid form. The voltaic battery, and the oxy-hydrogen blowpipe successively brought new substances within the law, and there cannot be a doubt in any mind, that all bodies which at common temperatures are solids, may be liquefied with a sufficiently intense heat, and under favourable circumstances. Astronomers assure us that there are worlds, in the universe, in which the most dense bodies existing on the surface of our globe would be liquefied, and it is equally true that there are others in which all known liquids would be solidified.

There are some substances, which, in passing from the solid to the liquid state, exhibit almost every degree of cohesion between the two conditions, and there are others which pass immediately from one state to the other. Bodies which have a crystalline structure, are of the former character, while ice, frozen mercury, and several of the metals, are of the latter.

Heat is well known to be the cause of fluidity, and it has been supposed to produce this condition in consequence of a repulsive influence induced upon the particles of all substances. Bodies, whether solid or fluid, have an attractive influence upon each other, and the particles of those bodies are united by the same force; heat is the antagonist power to cohesion, and the degree of solidity may always be attributed to its counter-acting influence. This is the general rule, but there are exceptions to it, which cannot be very readily explained. Assuming the statement we have made to be a principle, it is easy to perceive that every body should in passing from a solid to a liquid expand, because the cohesive power is lessened, and the repulsive increased:—so, on the other hand, when a liquid becomes a solid, it should contract, for the repulsive power is withdrawn; yet it is well known that some crystalline substances contract in fusion, and water expands when freezing.

The honour of discovering the manner in which heat is able to convert solids into liquids, and, as we shall presently have occasion to prove, liquids into vapours, is due to Dr. Black, Professor of Chemistry at the Glasgow University. His first conclusive experiment, made at the close of the year

1761, was a comparison of the time required to raise the temperature of a certain weight of water one degree, with that necessary to liquefy an equal weight of ice. In this way he was led to the discovery, that the heat required to liquefy a certain weight of ice, would give to an equal weight of water an increased temperature of 140°; the circumstances in both cases, being the same. Now, although so large an amount of heat is received in the process of liquefication, neither the sense of touch nor the thermometer can detect its presence. The water, which is obtained from melting ice has, at the moment of liquefaction, precisely the same temperature as the ice itself, and on this account Dr. Black proposed the term latent heat, as applicable to that which is received by bodies when they assume the liquid or vapourous form. It is hardly necessary to remark, that when a liquid is solidified, the latent heat, or caloric of fluidity, as it is sometimes called, must be given out.

The process of observation and thought which led Dr. Black to this important discovery, was so natural and simple that the reader will, perhaps, wonder that it has never struck his own mind, and that so many should have observed the same phenomena before his time, and not have come to the same conclusion. The Professor remarked, that when ice at a temperature below 32° was brought into a warm room, it gradually rose till it attained that degree of temperature. After this, it melted, and no increase of temperature was observed, until the whole mass of ice was liquefied; hence it appeared that the heat received by the body was gradually appropriated for the purpose of producing liquidity, without in any

degree causing an alteration of temperature. With this view of the influence of heat in producing the liquefaction of bodies, the Professor reasons on the great importance of that provision by which solids are compelled to receive a large amount of constituent caloric, before they can assume a liquid state. Let it be for a moment supposed, that at a certain degree of temperature ice, as an example, instantly became water; and it will be scarcely possible to imagine the amount of devastation to which all those places situated near mountainous districts would be subjected. The ice and snow which at one moment hung in a solid form upon the flanks of the mountains, might at the next assume its liquid form, and rushing into the valleys sweep away every opposing force in its fury.

There are two experiments made by Dr. Black, either of which will illustrate the phenomenon of latent heat. He first placed five ounces of pure water in each of two thin glass vessels of the same size and weight. The water in one of these was frozen, and that in the other was reduced to a temperature of 33°. In about half an hour the thermometer in the water had risen to 40° of Fahrenheit. When the ice had the temperature of melting snow, or 32°, the time was accurately marked, and in about ten hours and a half all the ice was melted, except a small spongy mass which floated upon the surface. In a few minutes more, the whole of the ice was liquefied. From this experiment it appears that a degree of heat, which will raise the temperature of water, seven degrees in half an hour, must be acting for ten hours and a half before ice can be raised to the same temperature,

so that if we multiply 7 by 21, the number of half hours, it will give the number of degrees of heat required, that is 147°; and deducting 8°, the increase of temperature obtained, it will give 139°, or according to calculations made in the same and in other ways by many chemists and philosophers 140°, as the quantity of heat required to liquefy five ounces of pure water.

The other experiment to which we referred was as follows:—a certain weight of ice at 32° was plunged into an equal weight of water at 176°; the ice was melted, and the temperature of the mass was reduced to 32°. This experiment will be better performed, and more accurate results will be obtained, if a pound of newly fallen snow be added to a pound of water at 172°; the snow will be melted, and the resulting liquid will have a temperature of 32°, which gives 140° as the quantity of heat absorbed in the process of liquefaction.

To these remarks we may add, as a suitable and comprehensive view of all that we know concerning latent heat, the observations of Professor Thompson. "It is rather difficult to ascertain the precise number of degrees of heat that disappear during the melting of ice. Hence different statements have been given. Mr. Cavendish, who informs us that he discovered the fact, before he was aware that it was taught by Dr. Black, states them at 150°; Wilcke at 130°; Black at 140°; and Lavoisier and Laplace at 135°. The mean of the whole is very nearly 140°.

"Water, then, after being cooled down to 22°, cannot freeze till it has parted with 140° of caloric; and ice, after

being heated to 32°, cannot melt till it has absorbed 140° of caloric. This is the cause of the extreme slowness of these operations. With regard to water, then, there can be no doubt that it owes its fluidity to the caloric it contains; and the caloric necessary to give fluidity to ice is equal to 140°.

"To the quantity of caloric which thus occasions the fluidity of solid bodies by combining with them, Dr. Black gave the name of latent heat, because its presence is not indicated by the thermometer; a term sufficiently expressive; but other philosophers have rather chose to call it the caloric of fluidity[1]."

SOLIDIFICATION.

All liquids excepting alcohol have been solidified, and all solids excepting the diamond have been liquefied. We may therefore conclude that heat is the cause why every substance exists in a particular natural condition, and it will be presently shewn, that by varying the action of that agent a new state may be obtained.

When a substance that is liquid at common temperatures assumes a solidified state, it is said to be frozen. Some liquids freeze at temperatures little below that which is a frequent atmospheric temperature, and others require the utmost intensity of cold that can be obtained by the ingenuity of modern philosophers. When substances that are

[1] System of Chemistry, p. 56.

solid at common temperatures become liquid, they are said to be melted or liquefied.

From the experiments of Fahrenheit, Sir Charles Blagden, and other philosophers, it appears that the common freezing point of water is 32°, but by avoiding any agitation of the liquid, freeing it from atmospheric air, and by taking great care in performing the experiment, the temperature has been reduced to 22° Fahrenheit, before it assumed the solid state.

Sea water requires a lower temperature for its solidification than pure water, a fact which is accounted for by the presence of salt. The same effect is generally obtained when the salts are dissolved in pure water. The following table gives the results of Sir Charles Blagden's experiments upon the freezing points of various solutions:—

Name of the Salt added.	Proportion.	Freezing point.
Common salt	25 per cent.	4 Fahrenheit.
Mur. ammonia	20 „	8 „
Tart. potash	50 „	21 „
Sulph. magnesia	41·6 „	25·5 „
Nitrate of potash	12·5 „	26 „
Sulphate of iron	41·6 „	28 „
Sulphate of zinc	53·3 „	28·6 „

From this table it will appear that the intermixture of common salt lowers, more than any other substance, the temperature of water. A knowledge of this fact enables us to account for the presence of salt in sea water, and is another evidence, if such were required, of the design so admirably displayed in all parts of the creation.

VAPORISATION.

Many solids and liquids may by an increase of temperature be converted into the gaseous state. When substances are giving off vapour, which many do, at common temperatures, and beneath their boiling points, they are said to undergo evaporation; but when the formation of vapour results from an increase of temperature, the process is called vaporisation. It is to the latter that we shall principally refer in the following observations.

The temperature at which a liquid will begin to boil cannot be determined from a knowledge of its properties, yet every liquid has its own boiling point. The following table gives the boiling points of a few substances which have been submitted to careful experiment:—

Ether	100°	Fahrenheit
Carburet of sulphur . . .	113°	,,
Alcohol, sp. gr. 0·813 . .	173·5°	,,
Nitric acid, sp. gr. 1·500 . .	210°	,,
Water	212°	,,
Muriate of lime	230°	,,
Muriatic acid, sp. gr. 1·094	232°	,,
Oil of turpentine	316°	,,
Sulphuric acid, sp. gr. 1·842	545°	,,
Phosphorus	554°	,,
Sulphur	570°	,,
Linseed oil	640°	,,
Mercury	456°	,,

The boiling point of a liquid, water for example, is by no means fixed, a variety of circumstances may interfere, sometimes raising and sometimes lowering it. Two of these we shall mention, and they will both admit of proof by simple experiments.

The first question to be considered is, whether liquids boil at the same temperature in all vessels? In answer to this question, we will give an abstract of a paper[1] by M. Gay Lussac on the experiments of M. Achard.

"The principal consequences," he says, "deducible from these experiments are

"I. That in a metallic vessel, water in a state of ebullition does not preserve a fixed degree of temperature; but that, on the contrary, though water may not cease to boil, its degree of heat is continually varying, and that this variation is chiefly produced by the action of the air, as well on the sides of the vessel as on the surface of the water; but that in a glass vessel the boiling water maintains a fixed and determinate degree of heat, without the external action of the air upon the sides of the vessel producing any alteration.

"II. That the nature of the vessel has no influence upon the degree of heat which the water assumes in boiling.

"The first of these consequences seems to me inaccurate, as far as it refers to the influence of the moving air upon the sides of the glass vessel; for it is difficult to conceive that, while that influence is very perceptible in metallic vessels, it should be absolutely nothing in vessels of glass. This

[1] Ann. de Chemie, x. p. 49.

point, however, I do not stop to discuss, because the experiments of M. Achard having been made in vessels of different capacity, and containing unequal quantities of water, do not present a sufficient uniformity of circumstances.

"The second consequence, that the nature of the vessel has no influence on the degree of heat which the water adopts in ebullition, is not admissible. Yet M. Achard has sometimes seen water boil at a more elevated temperature in a glass vessel, than it did in a vessel of metal; but as that difference did not always occur, he rejected it as accidental.

"I remarked some years back, that a thermometer upon which I had fixed the point of 100° centigrade, by boiling water in a tin vessel, did not stand at the same point in a glass vessel, though in all other points the circumstances seemed perfectly similar. The difference was greater than one degree, and as I could attribute it to no other cause, but the nature of the vessels, I concluded that water boils sooner in a metallic vessel than in one of glass.

"I by no means pretend to give the absolute measure of the difference which may exist between the boiling points of water in a metallic vessel, and in one of glass; on the contrary, I conceive that this limit is variable, according to the nature of the substance; and for the same substance according to the state of the surface; for it seems probable that it depends at the same time on the power of conducting heat, and upon the polish of the surfaces."

But there is a cause, atmospheric pressure, which has a much greater effect upon the boiling point of liquids. It is well known that if water be placed under an air pump, and

the air be withdrawn, it will boil at a temperature much less than that required to produce the same effect under the common atmospheric pressure. An experiment may be here mentioned, which very beautifully illustrates the alteration of the boiling point from a diminution of temperature. Take a glass flask, and filling it up to the neck with water, boil the liquid. While the water is boiling, place a cork that fits tightly in the mouth of the vessel, and remove the flask from the fire. When the boiling has ceased, pour over the vessel some cold water, and ebullition will recommence. The cause of this curious phenomenon is evident. When the cork is placed into the neck of the vessel, the atmospheric air has been excluded, and the vapour of the liquid has taken its place; but when the cold water is poured over the surface of the vessel, the vapour is condensed, and a vacuum is consequently formed, a condition sufficient at once to account for the ebullition that immediately recommences. This experiment is more illustrative of the effect of pressure than that which is sometimes made under the receiver of an air pump. If the reader should wish to perform the experiment in that manner, let him take a vessel containing water at nearly boiling temperature, but not in a state of ebullition, place it under a receiver, and withdraw the atmospheric air—the boiling point will be lowered, and a rapid ebullition will be observed.

If the atmospheric pressure be increased, the boiling point will be raised; it has even been stated that water may, when under enormous pressure, be made red hot without ebullition.

From what has been said, the reader will come to the

conclusion, that the state of all substances, whether solids, liquids, or vapours, is regulated by latent heat; a principle which enables us to account for a variety of results that would otherwise be altogether inexplicable. Thus for instance, the temperature of the atmosphere is always colder during a thaw, after a severe frost, than during the frost itself. When water is taking a solid form it gives out its latent heat, and consequently adds to the sensible heat of the surrounding atmosphere; but when ice is resolved into water, sensible heat is absorbed, and it is the atmosphere and surrounding bodies which supply the requisite quantity.

In the process of evaporation also, we have evidence of the universality of the doctrine of latent heat. At whatever temperatures liquids become vapours, they must be supplied with a certain amount of heat to assume a latent state. Hence it is that evaporation always produces cold. If a little ether, or any other liquid that evaporates quickly, be held in the hand, for a little time, an intense coldness will be felt, because the sensible heat of the hand is applied to the process of evaporation. For the same reason water may be frozen in the warmest room, under the receiver of an air pump. This experiment is in itself so interesting, and is at the same time so illustrative of the principle, which we have attempted to explain, that we may appropriately close our remarks on the subject by an explanation of the manner in which it is performed.

Take a watch glass filled with water, and place it over a larger vessel containing sulphuric acid. Introduce both

these vessels under the receiver of an air pump, and exhaust the air. The aqueous vapour will rise and be absorbed by the sulphuric acid; but the temperature of the water will be so much lowered by the absorption of its sensible heat to aid the evaporation, that it will after a short time freeze.

THE COMMUNICATION OF HEAT.

It must be evident to every one who has considered the nature of the phenomena around him, that there are some active physical laws which tend to establish an equality of temperature between all substances. If an iron ball be heated to redness, and then placed upon a stand in the middle of an apartment far from any other body, its heat is quickly lost, and the temperature is reduced to that of the air in the room. By whatever cause the temperature of a substance may be raised or depressed, as soon as the cause ceases to act, the effect produced becomes less and less evident until at last it vanishes altogether. Now there are two ways in which heat may be conveyed from one substance to another,—when they are in contact, and heat is then said to be conducted; and also when they are distant from each other, separated by space or a non-conducting medium, and heat is then said to be radiated. In the one case we may suppose the agent to be transmitted from particle to particle, and in the other to be communicated through space independent of conduction. Any substance raised to a high temperature will communicate a portion of its heat to

every substance near it, partly by conduction, and partly by radiation. If we suppose it to be surrounded by dry air and placed in a large apartment, there will be a continued communication until the temperature of every body in the room is reduced to the same degree. Both conduction and radiation will be active in producing the effect, and we may easily trace their influence. The body is of course surrounded by atmospheric air, and the particles in immediate contact will be heated; the specific gravity of these is immediately changed, and becoming lighter, they rise and leave the colder portions to occupy their place. There will, therefore, be a constant current of hot air rising from the body, produced by the conduction of heat to the surrounding atmosphere. But now place a thermometer beneath the radiating substance, at such a distance, that there can be no possible conduction of heat; or place the heated body and thermometer in an exhausted receiver, and there will still be a proof of communication, for the thermometer will rise, although there is no possibility of conduction. By this and other experiments it has been proved, that bodies having a temperature higher than the atmosphere by which they are surrounded, and the substances near them, transmit in every direction a portion of their caloric, and that in an unmeasurably short period of time. This effect is produced by the passage of calorific rays in straight lines, and is said to arise from radiation. If any proof were required of the actual transmission of heat, from one body to the other, it would be only necessary to place a screen of some substance, impervious to heat, between them; and no effect is then produced upon the re-

ceiving body. These remarks will explain what is signified by the terms radiation and conduction of heat.

In our attempt to illustrate the nature of those processes, by which heat is communicated, we shall endeavour to describe some simple experiments which may be performed by any of our readers. In the former part of this volume we have adopted the same plan, as far as possible.

The study of the natural sciences is supposed to be connected with such an outlay of money, as to prevent persons in the common circumstances of life, from the acquisition of a practical acquaintance with them. This popular error should now be removed, for all the experiments required to prove the fundamental truths may be made with a few instruments, easily obtained by most persons, and far less expensive than many of the luxuries of life. A valuable apparatus is required by the public teacher, but the student may easily construct, if he has a little mechanical skill, many of those instruments, which if purchased, would be most costly.

I. THE POWER OF BODIES IN CONDUCTING HEAT.

When we use the term conduction of heat, it must not be understood to convey any theoretical notion of the nature of the agent. The use of the term may be supposed to imply the active communication of heat, as a principle, from one body to another, or from one part to another of the same body; but we cannot be certain that this is the process by which the temperature is communicated. It may be as some

persons imagine, that the particles of matter, instead of transmitting the agent, may resist its progress, and that the effects produced, by what we term conduction, may arise from induction. It must, therefore, be understood that in the use of the term conduction, no theoretical opinion is advocated. There seems to be a general tendency, in all matter, to acquire a uniform temperature for a substance unequally heated, soon diffuses its increased temperature.

CONDUCTING POWER OF SOLIDS.

If heat be applied to any part of a solid substance, the increase of temperature produced in the part that is heated, will be communicated through the whole mass. All solids, however, do not conduct heat with equal velocity, a fact which must have been frequently observed by those who have paid the least attention to external phenomena. If for instance a bar of iron, and a rod of glass be placed in the flame of a candle or in a fire, and one rod be held in one hand, and one in the other, the iron will be too hot to hold before the glass is warmed. Iron, therefore, is a better conductor than glass.

There are many interesting experiments by which the unequal conduction of heat by solids may be proved. One or two of these we shall mention.

Take a number of metallic bars of the same size, and place them upon a stand made of some non-conducting substance. Upon one end of each bar place a small piece

of phosphorus and a lamp at the opposite end so constructed that it may convey an equal temperature to each. The heat thus communicated will be conducted by the bars, and their relative powers of conduction will be shown by the periods of time required to inflame the pieces of phosphorus. Some will be ignited in a very short period after the lamp is lighted, and others have a conducting power so comparatively tardy, that they will require exposure to the flame for double the time before the same effect is produced.

Take a smooth cylinder of iron and wrap a piece of writing paper tightly round it, so that there may be no interval between them The paper may be held over a spirit lamp without being inflamed. Then take a cylinder of charcoal, and after wrapping paper round it in the same manner, hold it over the flame and it will be speedily burnt. The cause of this difference of effect is very evident. The metal is a good conductor, and the heat communicated to the paper cannot therefore accumulate in any part, but is diffused. The charcoal is a bad conductor, and the heat does accumulate, and scorch or burn the paper.

Many experiments have been made with the intention of determining the relative conducting powers of solids. The densest bodies are generally the best conductors, but there are some exceptions. The metals are the best conductors with which we are acquainted, but platinum the densest of the metals has a very inferior conducting power. Furs, hair and feathers are the worst conductors, which is supposed to result from the quantity of air between their parts. It cannot however fail to strike the reader that in this, as in

numerous other instances, the Creator has made a provision for the comfort of his creatures; and by nature we are taught how to provide against the cold to which we may be exposed. In winter we provide ourselves with woollen clothing and furs, by this means retaining the natural warmth of the body in consequence of the bad conducting power of the substance by which it is surrounded.

The sensation of heat or cold is under some circumstances deceptive. If, for instance, the hands be dipped into a basin of water at a moderate temperature, and then into a basin of some hot liquid, the difference of temperature between them would seem to be greater than it is, and this will appear evident if the hands be removed from the hot into the cold medium, for the cold will then produce a much more intense sensation. But in other instances we may easily explain the sensations produced by substances from a knowledge of their powers of conduction. Any number of bodies may have precisely the same temperature, and yet if successively touched by the hand produce exceedingly different sensations. Let the substances be iron, wood, and charcoal, and let them all have the same temperature as shown by the thermometer. The iron will, when touched, appear to be colder than the wood, and the wood colder than the charcoal. This arises from the greater power of conduction possessed by one, than the other. Iron conducts best, and consequently carries away the greatest amount of animal heat in a given time. Hence it produces the greatest sensation of cold.

There are many instances in which a knowledge of the conducting power of solids may be applied in the arts. Furnaces

are frequently covered with a paste of clay and sand to prevent the escape of heat. To keep a substance which has a lower temperature than the surrounding air, at a fixed temperature, we surround it with flannel, and the same method would be adopted if its temperature were higher than that of the atmosphere.

Experiments have been made by several philosophers to determine the conducting power of solids, and the relation between that and their other properties. The following table will give the conducting power of a few of the metals, as determined by Dr. Franklin and Dr. Ure, the best conductor being placed at the top of the list.

Dr. Franklin's results.	Dr. Ure's results.
Silver.	Silver.
Copper.	Copper.
Gold. }	Brass.
Tin. }	Iron. }
Iron.	Tin. }
Steel.	Cast Iron.
Lead.	Zinc.
	Lead.

The results obtained by M. Despretz differ in part from those deduced from the experiments of Franklin and Ure. It may appear a very simple task to determine the conducting power of metals, but the results are liable to considerable errors in consequence of radiation. The following is a table of the results obtained by Despretz:

Gold. . . .	100
Platinum . .	98·1
Silver	97·3

Copper . . .	89·82
Iron	37·41
Zinc	36·37
Tin	30·38
Lead	17·96

Count Rumford made some curious experiments on the conducting power of the substances chiefly used as articles of dress. The method in which they were performed, and the results, are sufficiently interesting to be mentioned. "His method was to suspend a thermometer in a cylindrical glass tube, the extremities of which had been blown to a globe of one-sixth of an inch in diameter, the bulb of the thermometer being placed in the centre of the globe. It was then surrounded with the substance, and the instrument was heated in boiling water, and afterwards being plunged into a mixture of pounded ice and water, the times of cooling were observed. The following are the results, the number of seconds being marked, during which the thermometer cooled from 70° to 10° on Reaumur's scale: air 576″; raw silk 1284; wool 1118″; cotton 1046″; fine lint 1032″; beaver's fur 1296″; hare's fur 1315″; eider down 1305″. The relative conducting powers are inversely as the times of cooling: hare's fur and eider down are the worst conductors, lint the best.

"The relative conducting powers of these substances appear to depend on the quantities of air enclosed within their interstices, and the force of attraction by which this air is retained or confined. If their imperfect conducting power depended on the difficulty with which caloric passes through their solid matter, the relative degree of that power would be

as the quantity of the matter. The reverse, however, is the case. It was found, by varying the arrangement of the same quantity of matter, the conducting power was varied. The thermometer being surrounded with sixteen grains of raw silk, the time of cooling from 70° to 10° of Reaumur amounted to 1214″; with ravellings of taffeta 1169″; and with cut sewing silk 917″. Here it was obvious that the more dense the same matter was, or the less air it contained, diffused through its interstices, the caloric passed with more celerity. It is evident also, that the air remaining in the globe in these experiments, if the motion of its parts had not been impeded, would have been sufficient of itself to carry off the caloric more quickly than it actually was, for air in motion conveys changes of temperature with celerity, and hence the interposition of the fibrous matter must have acted principally by retarding the motions of the enclosed air, partly also by retarding the discharge of heat by radiation.

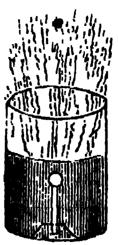
"The former effect will be in a great measure proportionate to their sponginess, and to the force of attraction with which the air is retained in their interstices. That such an attraction exists, is proved by the force with which they retain the air that adheres to them, even when immersed in water, or exposed under the receiver of an air pump. It is to this cause principally, that the property which all porous bodies, such as furs, feathers, wool and down, have of retarding the passage of caloric is owing."

CONDUCTING POWER OF LIQUIDS.

It is generally supposed by those who are unacquainted

with the science of heat, that liquids are good conductors. This opinion, however, is not supported by experiment, for Count Rumford proved, long since, that they possessed this property very imperfectly, and was himself of opinion that they had no conducting power. It has been since shown that liquids have a conducting power, though small in degree. Thus, for instance, water may be made to boil at the top of a glass vessel, without imparting sufficient heat to liquify ice one quarter of an inch distant from the surface.

Fig. 27.



The imperfect conducting power of a liquid may be proved by the following experiment. Place a small glass bulb and tube, containing air in a jar of water, so that the surface of the water may be a little above the top of the bulb; fig. 27. Upon the surface of the water pour a small quantity of ether and inflame it. If heat were conducted downward, the air in the bulb would be expanded, and the rise of bubbles of air would be observed. No such effect however is occasioned, and hence it may be deduced, that water does not readily conduct heat. A small thermometer will do as well for the experiment as a bulb and tube containing air.

Mr. Murray made a very interesting experiment for the purpose of ascertaining whether liquids had any conducting power, and its results were such as to prove that it had. We give the account in his own words:—"In a hollow cylinder of ice, a thermometer was placed horizontally, at the depth of one inch, its bulb being in the axis of the cylinder, and the part of the stem to which the scale was attached, entirely

without. As water could not be employed at the temperature at which it is requisite to make the experiment in this apparatus, on account of the property it possesses of becoming more dense in the rise of its temperature from 32° to 40°, oil was first used. A quantity of almond oil at the temperature of 32°, was poured into the ice cylinder, so as to cover the bulb of the thermometer a quarter of an inch. A flat-bottomed iron cup was suspended so as nearly to touch the surface of the oil, and two ounces of boiling water were poured into it. In a minute and a half, the thermometer had risen from 32° to 32¼°; in three minutes to 34½°; in five minutes to 36¼°; in seven minutes to 37½°; when it became stationary and soon began to fall. When more oil was interposed between the bottom of the cup and the bulb of the thermometer, the rise was less; but even when its depth was three quarters of an inch, its rise was perceptible, amounting to 1½ degrees. With mercury the same results were obtained, the thermometer rising only with much more rapidity, from the mercury being a better conductor than oil[1]."

The difficulty with which heat is conducted downwards by a liquid, may be proved by either of the following experiments.

Put some litmus water into a glass tube, and fill it up carefully with pure water. Apply heat to the top, and there will be no mixture of the two fluids for a considerable time; but apply the heat to the bottom, that is to the bulb, and they will be quickly united.

[1] Murray's System of Chemistry.

Place a piece of ice at the bottom of a glass jar, and upon it pour water at the temperature of 32°. Upon the surface of these place a small wooden box with minute holes in the sides, and pour into it boiling water gradually, till the vessel is nearly full, and in spite of the great amount of boiling water, it will be difficult to melt the ice. But if the ice be allowed to float upon the surface, it will very quickly disappear.

To show the currents which are formed by the circulation of heat through fluids, the following experiment may be made.

Fill a glass tube with water containing amber or some other substance not soluble in that liquid, and place the tube over a spirit lamp. The circulation of the particles will show the action of the currents, some ascending others descending.

From this last experiment it will appear that the slow conduction of fluids arises from the circumstance, that when fluids are heated they become specifically lighter, and hence cannot descend. But if heat be applied below, the lighter, that is, the heated particles rise, and the heavier or colder descend, and this continues until an equal temperature is established throughout.

CONDUCTING POWER OF ELASTIC FLUIDS.

Count Rumford was of opinion that gases and vapours, which comprehend that class of bodies called elastic fluids,

had no conducting power, and he proved by many experiments that it is very imperfect.

Experiments were made by Dr. Dalton, Sir H. Davy, and Mr. Leslie, for the purpose of ascertaining the conducting power of gases by the cooling of thermometer bulbs. Thus, for instance, Mr. Leslie ascertained that bodies cool more quickly in hydrogen gas than in atmospheric air, and in the latter than in carbonic acid gas. It would however be difficult to determine how much of the effect arose from conduction, and how much from radiation. There is reason to believe that the elastic fluids are conductors of heat, though very imperfect.

"In conclusion," says Dr. Murray, after speaking of the conduction of heat, "it may be observed that it is principally by the agency of fluids, elastic and non-elastic, that the distribution of caloric over the globe is regulated, and great inequalities of temperature guarded against; and that this agency is exerted chiefly by the circulation of which their mobility renders them susceptible.

"Thus the atmosphere, with which the earth is surrounded, serves the important purpose of moderating the extremes of temperature in every climate. When the earth is heated by the sun's rays, the stratum of air reposing on it receives part of its caloric, is rarified, and ascends. At the same time, from a law which attends the rarefaction of elastic fluids, they become capable of containing a large quantity of caloric at a given temperature as they become more rare; this heated air, though its temperature falls as it ascends, retains the greater part of its heat; its place at the

surface is supplied by colder air pressing in from every side; and by this constant succession, the heat is moderated that would otherwise become intense. The heated air is, by the pressure of the constant ascending portions, forced towards a colder climate; as it descends to supply the equilibrium, it gives out the heat it had received, and thus serves to moderate the extremes of cold. There thus flows a current from the poles towards the equator, at the surface of the earth, and another superior current from the equator to the poles; and though the directions of these are variously changed by inequalities in the earth's surface, they can never be interrupted, but produced by general causes must always operate and preserve more uniform the temperature of the globe. Water is not less useful in this respect in the economy of nature."

II THE RADIATION OF HEAT.

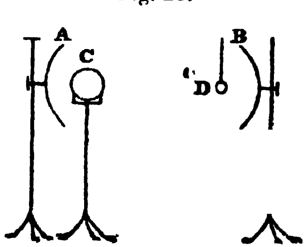
Mariotte appears to have been the first who observed, or at least experimented upon, the radiation of heat. The subject was first alluded to by this philosopher in the Memoirs of the Academy of Sciences in Paris. "The heat of a fire," he says, "reflected by a burning mirror is sensible in its focus, but if a glass screen be interposed between the mirror and the focus, is no longer sensible." This was an observation of great importance, and was afterwards closely examined by other philosophers. Lambert was one of the first to investigate the statement, and he endeavoured to separate the effect produced by light from that which resulted from heat. After having concentrated by a large lens

the light of a clear fire so as to receive it upon his hand, he was unable to detect any increase of heat; but he succeeded by the means of two concave mirrors in so reflecting the heat of burning charcoal as to ignite combustible bodies at the distance of thirty feet.

Scheele, in his celebrated treatise on air and fire, takes some notice of this subject, and introduces a description of some valuable experiments he had made. We are indebted to this celebrated man for the term radiant heat, by which he intended to convey the same meaning as might be expressed in the words heat flying off in rays. He also discovered that heat thus thrown off passed through space without any change of direction by the presence of air, and also that although a metallic mirror would reflect both heat and light, a glass mirror reflected the light only.

M. M. Pictet and Saussure repeated these experiments, and introduced an apparatus, fig. 28, which is used in the present day in all investigations on radiant heat. Their apparatus may be properly described, as explanatory of the means by which the student must make his experiments in illustration of the facts to be presently mentioned.

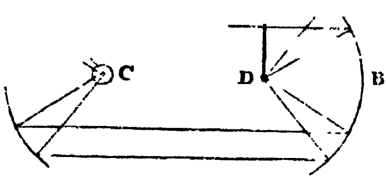
Fig. 28.



A B, are two concave mirrors of polished tin about one foot in diameter, and with a focal length of 4½ inches, placed exactly opposite to each other at the distance of twelve feet. C is an iron ball raised to a temperature just below that at which

it would be visible about two inches in diameter in the focus of the mirror A; D is the bulb of a thermometer in the focus of the mirror B. As soon as the heated ball is put into its place, the thermometer will rise and give evidence of an increased temperature. Another thermometer may be placed at the same distance, but out of the focus; and this, though in some degree affected, will not be acted upon to the same amount.

Fig. 29.



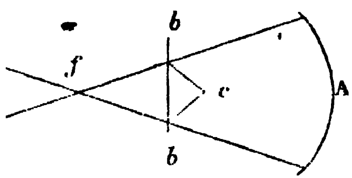
The effect produced may, we hope, be understood by the following explanation. Let the heated ball C fig. 29, be placed in the focus of the mirrror A, and some of the rays of heat which are projected from the heated body will fall upon the mirror by which they will be reflected in straight and parallel lines, towards the opposite reflector B, by which they will be again reflected, and brought to a point as at D, which is the focus. If then a thermometer be placed in this point where all the rays of heat are concentrated, it must necessarily rise.

REFLECTORS OF HEAT.

In experimenting upon the radiation of heat, it is customary to use metallic reflectors, polished tin being generally chosen for the purpose. All polished surfaces do not reflect heat equally. Glass is a much worse reflector than metal,

and a mirror covered with ink refuses to reflect any portion of the heat that is thrown upon it. Sir John Leslie, to whose labours we are much indebted for our knowledge concerning radiant heat, made a long series of experiments, with the view of determining the reflecting powers of different substances. To obtain great accuracy of result, and to prevent the necessity of forming a new mirror for every experiment, he adopted the following excellent arrangement: fig. 30. A is a metallic mirror; *f* its focus, where all the rays of heat are concentrated; *b b* is a reflecting body placed at some distance between the mirror and its focus. The rays being intercepted by the reflecting surface before they reach the focus, will be thrown back, and meet in a point *c*, as far before it as they would have otherwise been behind it. The reflector *b b* may be readily changed, and the power of the bodies placed in the same situation compared by the effects which they may have upon a thermometer placed at *c*. In this manner Professor Leslie ascertained the reflecting power of several substances; some of his results are given in the following table:—

Fig. 30.

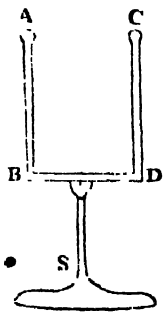


Brass . . .	100	Lead	60
Silver . . .	90	Tinfoil softened with mercury	10
Tinfoil . . .	85	Glass	10
Block Tin . .	80	Ditto coated with wax or oil .	5
Steel . . .	70		

A thermometer is not well adapted to measure radiated

heat, for it registers any casual variation in the temperature of the atmosphere as well as the intensity of the radiated heat. If a thermometer be used for the experiments, a second should be provided and placed near the other, but entirely out of the reach of the radiated heat, and by its indications the observer may correct any error arising from an alteration of temperature in the atmosphere. But Sir John Leslie has invented an instrument, fig. 31, the differential thermometer, which is not affected by any change of temperature in the atmosphere, since both its bulbs are acted upon equally.

Fig. 31.



It consists of a glass tube A, B, C, D, supported on a stand S. A small quantity, sufficient to fill the horizontal part of the tube and one leg, of coloured sulphuric acid is placed in the tube, and a bulb is formed at the ends A and C. When the two balls are exposed to an equal temperature, the fluid rises to the same height in both arms; but when one is more heated than the other, the expansion of the enclosed air forces the liquid up the opposite part of the tube. To one arm a scale is attached by which a comparison may be formed between the temperatures to which the instrument is subject at different times, and the bulb on it is called the focal ball.

TO SHOW THE RADIATION OF HEAT.

Take two concave metallic reflectors A and B, (*see fig.* 28.)

and place them opposite to each other at a convenient distance. In the focus of the mirror A, put a hot ball, and in the focus of the mirror B, one bulb of the differential thermometer, that to which the scale is attached, and the dry air contained in it will immediately begin to expand and drive the coloured fluid into the other bulb.

Place a red hot ball in the focus of one mirror, as in the previous experiment, and gunpowder, or some other substance easily inflamed, in the other, and it will soon be exploded by the radiated heat.

The experiment may be varied by placing a piece of phosphorus in the wick of a candle, and fixing it in the focus of the mirror B. The phosphorus will be inflamed, and the candle lighted.

It may be well to remark that we learn from the first experiment, that heat unconnected with light is capable of both radiation and reflexion. The ball employed is supposed to have a high temperature, but one below that at which heat becomes luminous. We have, therefore, a proof that the effect does not depend upon the presence of light, for although light and heat are frequently blended, they may have a separate existence.

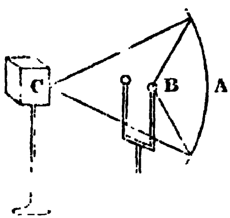
M. Pictet endeavoured to ascertain the velocity of radiant heat, and for this purpose placed two concave metallic reflectors opposite each other at a distance of sixty-nine feet. The instant that the heated ball was placed in the focus of one mirror, the thermometer in the other was affected. It was, therefore, evident that the effect was transmitted with great

velocity, but the actual rate has not, and cannot be very easily determined.

RADIATING SUBSTANCES.

All substances do not radiate heat equally, and it was suggested to Sir John Leslie, by previous experiments, that this probably arose from the nature, of their surfaces.* The means adopted to determine this question may be here described, and the experiments easily repeated by the reader.

Fig. 32.



A, fig. 32, is a metallic reflector, B is its focus in which the ball of a differential thermometer is placed; C is a tin canister, the sides of which may be covered with different substances. Let the canister be filled with boiling water, the surface nearest to the reflector will radiate its heat in that direction, and the rays will be reflected to a focus where they will act upon the ball of the thermometer. Let it then be supposed that one side is left uncovered, one coated with lampblack, another with isinglass, and the fourth with ink. When these surfaces are severally presented to the reflector they will be found to produce different effects upon the thermometer. The lamp black radiates most, the ink next, then the isinglass, and the tin least. The metals are the worst radiators, as in fact we might expect, for they are the best reflectors; and it has been established as a general law, that

the best reflectors are the worst radiators, and also that the best radiators are the worst reflectors. The following table gives the relative powers of radiation possessed by some substances as determined by Sir John Leslie:—

Lamp black . . .	100	Isinglass	80
Water by estimate	100	Plumbago	75
Writing paper . .	98	Tarnished lead . .	45
Resin	99	Mercury	20
Sealing wax . . .	95	Clean lead	19
Crown glass . .	90	Iron polished . . .	15
China ink . . .	88	Tin plate	12
Ice	85	Gold, Silver, Copper	12
Minium	80		

From this table it might be supposed that the condition of roughness or smoothness would have some effect upon the radiating power of any surface. The radiating power of tarnished lead is represented by the number 45, while clean lead is only 19. From a variety of experiments it is certain that the more polished surfaces radiate less heat than the rough ones, and as an illustration of this fact, the following experiment may be tried.

Take a tin canister, as already described, and let one of its sides be highly polished, and another scratched with a piece of sand paper. Turn them severally when the canister is filled with hot water to the reflector, and the thermometer in its focus will be more affected by the heat thrown off by the rough, than the smooth and polished side.

We are also indebted to Leslie for another important fact, —that within certain limits the radiation increases with the

thickness of the radiating substance. Thus for instance, two sides of a vessel containing hot water were covered with a jelly, one having a coating four times as thick as the other,—the surface which had the greater quantity radiated most. The same result was obtained with other substances. Great thickness, however, is not required; for in the experiment just mentioned, the increase of radiation was not observed after the thickness of the coating amounted to more than about one thousandth part of an inch.

There may be some of our readers who will now be ready to enquire what would be the effect of placing a cold body in the same situation as the canister of hot water? Would it not radiate cold and cause the liquid to rise into or towards the bulb of the thermometer placed in the focus of the mirror? It is true, that this effect would be produced, but the radiation of cold is not the cause. All substances radiate heat whatever may be their temperature, and they all receive or reflect the heat that falls upon them. If we were to place a mass of ice in the same situation as a canister of hot water, the ice would radiate some heat, but the ball of the thermometer would also radiate, and as it would have the higher temperature, it would radiate more than the ice, and the rays thrown off from it would be reflected from the mirror towards the ice. The liquid, therefore, rises in the focal arm of the thermometer, not because cold is radiated from the ice, but because it is in the act of radiating heat.

These remarks lead us at once to another enquiry connected with the subject of radiation. We have spoken of the substances which reflect heat, and of those which radiate

it, but neither the reflexion nor radiation could be ascertained, if there were not some substance to receive the heat thus made ready to be communicated; we must, therefore, now refer to the power of absorption.

ABSORPTION OF HEAT.

The effect produced upon the thermometer ball by the reflexion of the radiant heat, must entirely depend upon its receiving the heat communicated, that is, in other words, upon absorption. When heat falls upon any substance it must either be reflected or absorbed; it must be either driven from its surface, or increase its temperature. This is evidently the case in relation to all the bodies with which we are acquainted, and a not less evident deduction may be drawn from it—that those substances which reflect best must be the worst to absorb, for they cannot receive much if they reflect a great deal. The reverse of this statement is equally true, for if a substance absorbs readily, it can have but small powers of reflexion.

In all the experiments hitherto described, the glass bulb of a thermometer has been used as the medium for the action of the concentrated heat, and we have already shown that glass is as bad a reflector as polished tin is a good one; cover the bulb with tinfoil, and place it in the focus of the mirror, and it will be soon discovered, that the effect produced upon the thermometer is much less than when the uncovered polished glass ball was used.

Experiments made upon a variety of other substances have led to the general law, that as the power of reflexion decreases in any substance its power of absorption increases. But it has been already stated, that the radiating power increases as the reflecting power decreases; therefore, the power of absorption and of radiation will increase together. This fact might have been deduced from a consideration of principles, but is proved by experiment.

Let us take an example:—the polished metals are good reflectors, but they are bad radiators, and they are equally inferior in their power of absorption. We find that they are good reflectors when employed as mirrors; we know that they are bad radiators, for when a polished metallic vessel containing hot water is placed before a mirror, little effect is produced on a thermometer in the focus of reflexion, and to give a very familiar instance of their deficiency in the power of absorption, we may refer to the well known fact that a polished fender or a set of fire irons, may be before an intense fire for many hours, without much increase of temperature.

Allusion has now been made to some of the most important general facts relating to the reflectors, radiators, and absorbents of heat. We have spoken of those substances which are best adapted to throw off, in rays, the heat that is communicated to them; those which most readily reflect it; and those which most readily absorb it. There is yet one other question to be considered, do all substances give equal facility to the passage of radiant heat? We are not now required to examine the conducting powers of bodies, but the

resistance or non-resistance offered by substances to the passage of rays of heat. We know, as the result of experiment, that heat may be radiated in a space as free from air as we can obtain by artificial means; we wish, therefore, to know whether there are any substances in nature which have a tendency to retard the progress of this radiated heat. We wish to know what substances are permeable to the rays of heat, that is, through what bodies the rays can pass, and consequently what bodies retard their progress. We may, therefore, class our observations under the general title

THE PASSAGE OF RADIANT HEAT.

There is a close connexion between the effects produced by heat, and those which result from light. It may not then be improper to take an illustration of our present subject from the effects produced in the transmission of light, although the cases are not precisely analogous. There are some substances which transmit light readily, there are others which offer an irresistible obstacle to its progress—the former are said to be transparent, the latter opaque. Glass, water, and air are transparent substances; metal, stone, and wood are opaque. Thus it is with the rays of heat, some bodies may be transparent to them, that is, admit their passage, others may be opaque, or resist their progress. We must now endeavour to ascertain which are pervious, and which impervious to the calorific ray.

To illustrate this subject a reference may be made to an

experiment already described; *see* fig. 28: A and B are the reflectors, C the heated ball, and D a bulb of the thermometer. Now there is atmospheric air between the heated ball and the reflectors, and as an effect is instantly produced upon the thermometer, the air can have little power to resist the passage of radiant heat; or in the terms usually employed by scientific men, it is pervious. The same is true of all the gases, for it has been proved by Leslie and others, that an equal effect is produced upon the thermometer, whichever of them may be between the radiant body and the reflector.

The bodies which radiate worst, that is, reflect most, are found to be most active in preventing the passage of heat, and are consequently used as screens when it is necessary to prevent the effect of radiant heat. This has been proved by experiment, but might have been anticipated from the statements already made, for it is evident that those substances which have the power of reflecting much of the heat that falls upon them, can have little power of transmission. The entire subject depends upon this one question, "Is the substance under consideration most capable of reflecting or of transmitting heat?"

The metals, even when reduced to extreme tenuity, entirely intercept radiant heat. A gold leaf, it is said, so thin that 300,000 of them would not be an inch in thickness, is sufficient to stop the rays. A deal board will produce a similar result, but in a less degree, for some effect will be produced through one an inch in thickness. Glass also, is capable, in some degree, of intercepting radiant heat.

Take a canister containing boiling water, and place it oppo-

site to a reflecting mirror, and register the effect produced upon a differential thermometer in a certain time; then return the thermometer to the state in which it was previous to the first experiment, and place a glass screen between the reflector and the thermometer;—the thermometer will now be affected in a much less degree than before. This experiment will prove that some substances intercept the rays much more than others.

Sir John Leslie also determined the effects produced by an alteration of the distance between the screen and the radiant body. The nearer the screen was placed to the radiating substance, the greater the effect; and as the distance between them increased, the effect upon the thermometer decreased, and was soon entirely destroyed.

M. De la Roche entered into an investigation of the power possessed by radiant bodies at different temperatures to penetrate screens, and proved that the power of the rays increases with the temperature of the radiating body. This is a most important fact, and deserves consideration in every experiment when screens are employed.

We have now considered the most remarkable phenomena which attend the radiation, reflection, absorption, and transmission of radiant heat. From what has been stated it may be supposed that the surfaces of all bodies in some degree radiate, reflect, and absorb, and are constantly exercising all the three properties. There must, therefore, be a continual interchange of heat between them, and at the same time a tendency to establish a uniform temperature. The heat radiated by one body may be reflected by another, but must be ab-

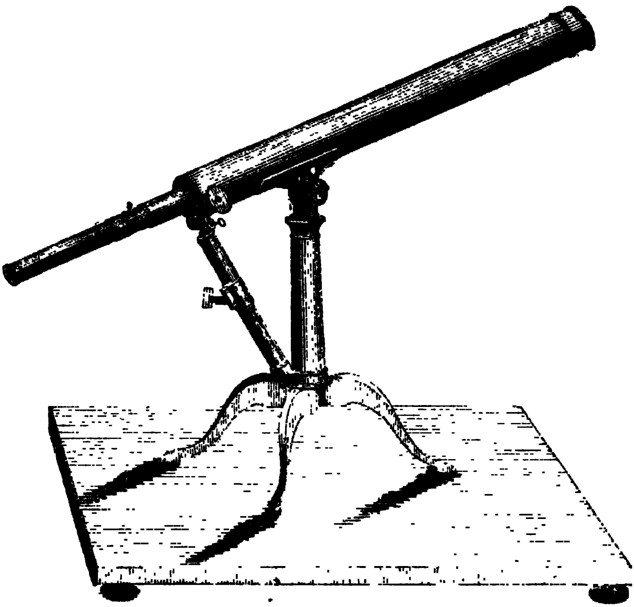
sorbed by some one, while at the same time the body which we suppose to be radiating heat must be receiving it from other substances. We may, therefore, consider every substance as a radiator, but the quality may be either in a greater or less degree. There is an evidence of design in the fact that those bodies which radiate best, absorb most; for if it were not so arranged, they would be constantly decreasing in temperature, that is, if we suppose them to give out more heat than they receive. And so, if those substances which have little or no radiation had great absorbing power, their temperature would soon be raised higher than that of all other substances, and to the increase there could, as far as we know, be no end.

We might mention many instances of the application of these facts to the arts, one or two will be sufficient to illustrate the observations we have made, and to impress the principles upon the mind of the student.

Every body which is required to retain a high temperature, should have a surface that is a bad radiator, and since bad radiators are good reflectors, the same surface is well adapted to prevent the absorption of heat, and keep a cold body contained within it at a low temperature. It is commonly supposed among a particular class of persons that tea may be kept warm for a much longer time in a common black porcelain pot, than in a Britannia metal, or bright silver teapot. No opinion can be more opposed to the results of experiment, for we have stated proofs that bright metallic surfaces are almost incapable of radiation, and it might easily be

proved, that few substances can radiate better than black porcelain.

To keep an apartment cool, greatly exposed without to intense heat, nothing could be better than to surround the outside with polished metal, which would reflect nearly all the heat thrown upon it. The heat which is suffered by a man wearing bright armour, does not arise from the passage from without, but from the great inabilityof the metal to radiate the heat from within. A bright steel dress would, in fact, transmit less of the heat of the sun, than a suit of woollen clothing. In our work on the Earth, the reader will find some instances of the agency of these principles, in producing natural phenomena.



REFRACTING TELESCOPE.

CHAPTER V.

OPTICS.

INTRODUCTORY REMARKS.

More than two thousand years have passed away since Aristotle, the earliest writer on optics, whose treatise has come down to our own times, penned his unsuccessful paper. About fifty years after, the celebrated Euclid wrote a work

on the same subject, in which he maintains that "visual rays issue from the eyes in diverging right lines, so as to form a pyramid or cone, whose vertex is in the eye, and whose base encircles the object we contemplate." In the year B.C. 218, Archimedes flourished and invented his burning mirrors. A few years after, Ptolemy Euergetes fixed his great mirror on the tower of the Pharos at Alexandria. In the twelfth century the celebrated Arabian Philosopher wrote his Treatise, afterwards published under the title "Thesaurus Opticæ;" and during the three following centuries arose Bacon, Porta, Maurolicus, and Kepler. The seventeenth century produced Antonio de Dominis, Harriot, Boyle, Hooke, Grimaldi, Leibnitz, Barrow, and the pride of England, Sir Isaac Newton. Since the days of Newton, the science has been held in high esteem by Philosophers, and the many discoveries recently made, have acquainted us with so many curious facts, that it may now be fitly denominated the most beautiful and diversified of all the Physico-Mathematical sciences.

There has been a great difference of opinion concerning the nature of light, and in the present day writers are by no means agreed upon this curious enquiry. It is said that Timæus, who wrote a Treatise on the Nature of the Soul of the World, supposed light to be an immaterial essence. Des Cartes imagined it to be produced by undulations excited in an ether of extreme rarity. Sir Isaac Newton taught, that light consists of a vast number of exceedingly small particles emitted in all directions from the luminous body. These particles are said to be thrown out with an amazing velocity in right lines, and may be deflected out of their course by

processes called reflexion and refraction. It is not our intention to examine the arguments by which these theories are supported, but shall at once proceed to explain the effects produced upon light by substances of different kinds. The only preliminary statement necessary to be understood is, that light moves in right lines, a fact discovered by the disciples of Plato, and clearly proved by the form of shadows, and by the direction of a ray admitted into a darkened room.

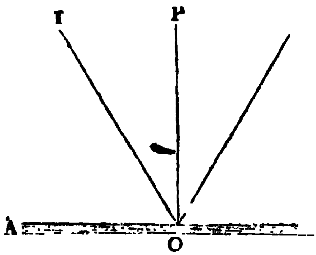
REFLEXION OF LIGHT.

When a ray of light proceeding in a right line from any luminous body is intercepted in its course by a mirror, it is thrown back again, or reflected, and made to move in a direction different, and sometimes opposite to that it was taking at the moment of interruption. The direction of the ray after reflexion will depend on the form of the surface which reflects, without regard to the composition of the substance; to determine this is our present object, without attempting to describe any of its acquired physical properties after reflexion.

1. When a ray of light is incident on a smooth polished plane, a portion of it is reflected, and the reflected ray will be on that side of the perpendicular opposite to the incident, and will make an angle with it equal to that of the incidental ray.

Let A B, fig. 33, be a plane mirror, or any other reflecting surface, and I O a ray of light incident upon it, the ray will be reflected in the direction O R; so that the angle

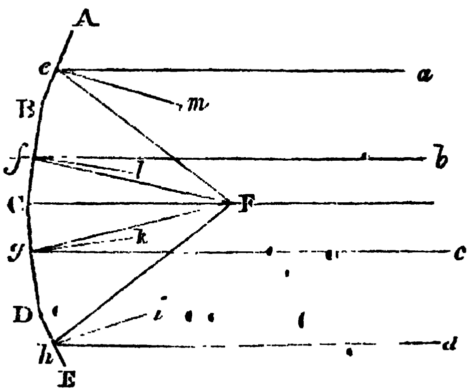
Fig. 33.



POR, called the angle of reflexion, shall be equal to the angle POI, which is the angle of incidence. Now this is true in every case, and therefore, it is stated that the angle of reflexion is equal to the angle of incidence. This is the first and fundamental law of reflexion.

II. When parallel rays fall upon a concave reflecting surface they will converge, and meeting will cross each other at a point called the focus.

Fig. 34.

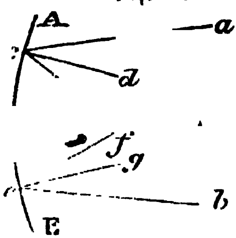


A curved surface can only be considered as composed of a vast number of almost infinitely small plane surfaces inclined to each other. Let AB, BC, CD, DE, fig. 34, represent any of these planes, and let parallel rays *a*, *b*, *c*, *d*, fall upon them. Let *em*, *fl*, *gk*, and *hi*, be lines perpendicular to the inclined planes. Then the angles *aem*, *bfl*, &c., will be the angles of incidence, and as the angles of reflexion are equal to them, and on the opposite side of the perpendicular, they will be represented by *m e* F, *l f* F, &c.: the reflected

rays must, therefore, converge and meet in a focus. The converse of this is also true; for if rays diverge from the focus of a concave surface as at F, they will be reflected parallel to the axis of the concave surface.

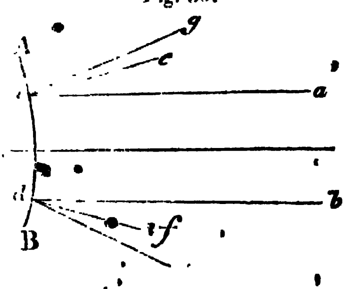
III. When converging rays fall upon a concave surface, they will be reflected converging, and meet in a point. Let *a c* and *b e*, fig. 35, be two rays converging to some point beyond the mirror A E, and let them be intercepted, the rays impinging on the points *c* and *e*; and let *d c*, *g e*, be lines perpendicular to the planes of those parts of the curve, then the reflected rays will be in the direction *c f*, *e f*, and the rays will converge to, and cross each other at the point *f*.

Fig. 35.



IV. When parallel rays of light fall upon a convex surface and are reflected by it, they diverge. Let A B, fig. 36, be a convex surface, and *a c*, *d b*, two incident rays impinging upon the curve in the points *c* and *d*. Let *e c*, *f d*, be perpendiculars to the curve at the points *c* and *d*; *e c a*, and *f d b* are the angles of incidence, and the angles of reflexion must be equal to them on the opposite side of the perpendiculars *e c*, *d f*, that is *e c g* and *f d q*.

Fig. 36.



We might now proceed to speak of the appearances pre-

sented by images after reflexion from plane and curvilinear mirrors, but this subject may be more properly introduced when we describe the character of optical instruments.

REFRACTION OF LIGHT.

It has been doubted whether the refraction of light was known before the time of Pythagoras. Dioptrical phenomena are, no doubt, much less frequently observed, than those of reflexion, but they are too numerous for us to suppose that they were unnoticed by even the first inhabitants of the earth. The shepherd, the traveller, and the husbandman, in the earliest ages must have frequently seen, and made many attempts to investigate, these curious appearances.

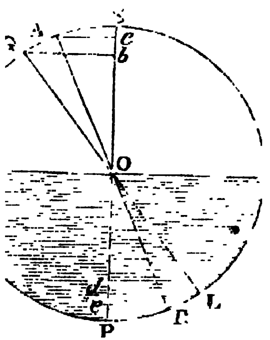
When a ray of light falls upon a transparent uncrystallized medium a portion of it is dispersed in every direction, and by the scattered part of the ray the surface is made visible; another portion is reflected, and the remainder enters the medium.

In reflexion from a surface the law governing the direction of the reflected ray is the same, whatever may be the nature of the reflecting medium. But when light is refracted, the direction of the refracted ray will be different according to the nature of the medium through which it passes. There are, however, certain principles which are universal, and these will enable us to determine the direction of the refracted ray, whatever may be the nature of the substance by which the refraction is produced.

I. The fundamental law of refraction is this: The sines of the angles of incidence formed by any two rays incident on any medium, have the same proportion to the sines of the angles of reflexion; and this law is true for both plane and curved surfaces.

Let DSDP, fig. 37, be a circle; DOD and POS two diameters perpendicular to each other. Let AO be a ray of light incident upon the surface DOD, which we may consider as the surface of water. The ray will not pass through the water in a straight line, but will be bent or refracted at O into the line OR. The angle made by the incident ray with the perpendicular, that is the angle AOS, is called the angle of incidence, and POR the angle of refraction. eA is the sine of the angle of incidence, and cR the sine of the angle of refraction. Now let GO be another incident ray, and OL the refracted ray, Gb is the sine of the angle of incidence, dL, the sine of the angle of refraction. Now Gb will have the same proportion to dL, as Ae has to Rc. Hence it will appear that when any two or more rays of light fall upon the same medium at different angles of incidence, the sines of the angles of refraction will have the same proportion to their respective angles of incidence.

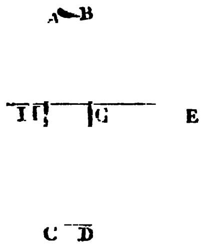
Fig. 37.



II. When a ray of light falls perpendicularly upon the sur-

face of a refracting medium, whose sides are parallel to each other, it will pass through that medium in the same direction, and in the same straight line, and therefore, does not suffer refraction.

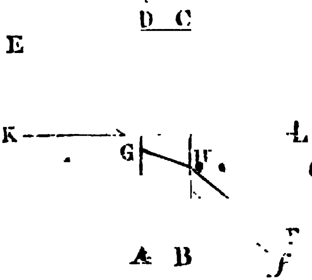
Fig. 38.



Let F E, fig. 38, be a ray incident at the point H, upon the surface A C of the medium A B C D. The ray will immerge at G, and have the same direction, and be in the same right line as FH, and therefore does not suffer refraction.

III. When a ray of light falls obliquely upon the surface of a refracting medium whose sides are parallel to each other, it passes through that medium, in the same direction, but not in the same straight line.

Fig. 39.

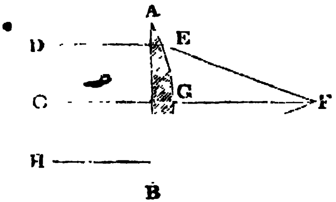


Let E G, fig. 39, be a ray of light incident on A B C D, at the point G. After passing through that medium it will take the same direction, though it will not move in the same straight line as previous to refraction; for how much soever the ray may be bent out of its direction at the first surface of the glass, it will be refracted as much in the opposite direction at the second surface. Although the ray E G does suffer refraction at G, and is, therefore, prevented from passing in the line Gf,

it is also equally refracted when passing from the glass, into the air at the point H, and the refracted ray H F is parallel to the line G*f*, which would have been the direction of the ray, if it had not been refracted.

IV. When parallel rays fall perpendicularly upon the plane surface of a refracting medium, the other surface being convex, they converge and are refracted to a point.

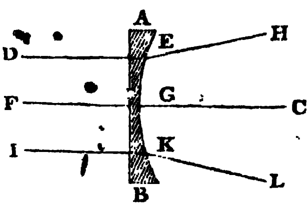
Fig. 40.



Let CG, DE, HI, fig. 40, be parallel rays of light falling perpendicularly upon the plane surface AB. CG not only falls perpendicularly upon the plane surface A B, but also on the convex surface A G B, and therefore, moves on without suffering refraction. The rays D E and H I fall obliquely on A G B and are, therefore, refracted: the point F where they cross is called the focus.

V. When parallel rays of light fall perpendicularly on the plane surface of a medium, the other surface being concave, they are refracted diverging.

Fig. 41.



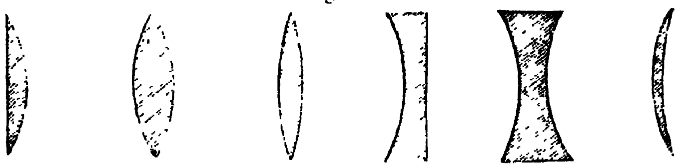
Let F G, D E, I K, fig. 41, be the incident rays. FG passes through the medium without refraction, for the reason already stated in previous problems. But in all other positions the rays are refracted diverging, D E to H, and I K to L.

All the effects which we have endeavoured to illustrate are

true, whatever may be the nature of the refracting substance. Of all transparent solids glass is most frequently employed. There are many substances which have greater refracting powers, but there are none which can be obtained with so much facility, or be ground and polished with so much ease. Still there are many objections to its use, and particularly that of the production of colour.

There are six shapes into which glass is frequently cut for the purposes of refraction. These are called lenses, and are represented in the following diagram.

Fig. 42.



1. 2. 3. 4. 5. 6.

No. 1, is a plano-convex lens having one side plane, the other convex: 2 is a double convex having both sides equally convex: 3 is a crossed lens, and its surfaces are of unequal curvature: 4, is a plano-concave lens: 5, a double concave lens: 6, a meniscus.

It does not appear that the ancients were acquainted with the real cause of refraction, although they had a knowledge of some of the most important phenomena. The first rational explanation to be met with on the subject is said to be in the Treatise on Optics, by Claudius Ptolemy, who assigns the changes made on incident rays to an attractive power in the medium through which they pass.

Archimedes, who lived 1350 years before Ptolemy, wrote a

treatise on the appearance of a ring under water,—which is a phenomenon entirely owing to refraction. In the life of Pythagoras written by Jamblicus, (it is not decided whether it is the Syrian, or he that was born at Colcher, for they were contemporaries,) an incidental allusion is made to optical instruments which magnify objects. These must have been convex lenses. Pliny observes that Nero made use of emeralds, whose surfaces were convex, to assist him in viewing exhibitions. Seneca knew that the rays of the sun, when they fall upon a triangular prism, are refracted, and colours are produced; and he says "letters, though minute and obscure, appear larger and more distinct when viewed through a glass bubble filled with water." But these bubbles were probably known long before the time of Seneca. They are not unfrequently found in places where Druidical remains have been discovered, and with them lenses of rock crystal of a regular form and polished. Some of these are globular, others lenticular;—One an inch and half in diameter was given by Dr. Woodward to the University of Cambridge. It is probable that these lenses were used for the purpose of ignition; but whoever had occasion to handle or use them, must have observed their magnifying power. There are many passages in the ancient writings, which relate to the same subject, and might be quoted. One or two will be sufficient. Aristophanes, in his Tragedy of "The Clouds," which was written to ridicule Socrates, introduces that great man as examining Stripsiades on his method of getting rid of his debts. "I'll use the glass I light my fire with; and if they bring a writ for me, I'll place my glass in the sun, at a short distance

from it, and set it on fire." Pliny says, that globes of glass, if exposed to the sun, will fire cloth, and may be used instead of caustics. Plautus also mentions burning glasses.

Alhazen, who wrote on many optical phenomena, has spoken of refraction, in the explanation of which he adopted the opinions of Ptolemy. He was not ignorant of the refracting power of the atmosphere, in elevating the heavenly bodies, and in giving them a false altitude; he also proved that from the same cause the vertical diameter of the sun and moon are apparently contracted, and believed it to be the origin of the twinkling of the stars.

Vitellio, who wrote a Treatise on Optics, showed that when light passes through any medium, a considerable portion of it becomes extinct. He also formed a table of the different refractive powers of air, water, and glass, and proved that refraction was necessary for the production of the rainbow.

Roger Bacon accounts for the superior magnitude of the stars when seen on the horizon than on the zenith, in the following manner. "The rays of light coming from the stars are made to diverge from one another, not only by passing from the rare medium of ether into the denser one of our surrounding air, but also by the interposition of clouds and vapours arising out of the earth, which repeat the refraction and augment the dispersion of the rays, whereby the object must needs appear magnified to the eye."

John Baptista Porta was the inventor of the Camera Obscura. This singularly ingenious philosopher formed an association, called "The Academy of Secrets," and published before he was fifteen years old, his "Magia Naturalis," in

which he describes the Magic Lanthorn, and the instrument already mentioned.

Shortly after the time of Porta, Snellius discovered the method of measuring refraction by means of the sines. Many persons have given the honour to Des Cartes, but Huygens declares that he transcribed it into his works from the papers of Snellius. We are, however, much indebted to Des Cartes, and Dr. Halley pays him a just tribute of honour, when he says, "although some of the ancients mention refraction as the effect of a transparent medium, yet Des Cartes was the first who reduced Dioptrics to a science."

CHROMATICS, OR THE THEORY OF COLOUR.

We have hitherto considered light as a simple substance of a white colour. But a beam of white or solar light is capable of decomposition, and is found to consist of seven differently coloured rays. This fact was discovered by Sir Isaac Newton, and may be proved in the most striking manner by the following experiment. Let us admit through a small round hole in the window shutter a ray of light into a dark room. If this be received on a white screen, it will present the appearance of a round white spot, which will increase in size, as the screen is removed to a greater distance from the hole. But, now place a triangular prism of good flint glass in the path of the ray, and let it be in such a direction that one of its angles may be downwards, the beam falling on one side obliquely. The light passing through

the glass will be refracted and thrown upwards, and may be received on a screen, or the white surface of a wall or ceiling. Upon this screen a long streak of vivid colours, usually called a spectrum, will be observed. The lower extremity is a brilliant red, which passes into an orange, and is succeeded by a pale straw yellow; a pure and intense green, succeeded by a blue deepening into a pure indigo, are next in order, and a violet forms the other extremity of the spectrum. Any of these colours may evidently be obtained separately, for if a small hole be made in the first screen, it may be so adjusted as to admit any one of the rays to pass, and fall upon a screen situated behind it. From this experiment we might be induced to enquire whether these insulated rays may not be again decomposed; the attempt has been made by placing another prism between the two screens, and allowing a ray of either coloured light to pass through it: refraction will be observed, but there will be no further change of colour. As we can analyze white light it may be supposed that it can also be recomposed, which is true. If for instance we admit a ray of light upon a prism, and throw the spectrum upon a convex lens, a spot of white light will be formed on a screen placed behind it.

Mac Laurin, Newton's faithful commentator, in detailing the experiments of that philosopher, makes the following remarks, which may be quoted as accurately expressing the opinions of his author :—"The sun's direct light, is not uniform in respect of colour; not being disposed in every part of it to excite the idea of whiteness which the whole raises; but on the contrary, is a composition of different kinds of

rays, one sort of which, if alone, would give the sense of red, another of orange, a third of yellow, a fourth of green, a fifth of light blue, a sixth of indigo, and a seventh of violet; that all these rays together, by the mixture of their sensations, impress upon the organs of sight the sense of whiteness, though each ray always imprints there its own colour; and all the difference between the colours of bodies when viewed in open day-light arises from this, that coloured bodies do not reflect all sorts of rays falling upon them in equal plenty; the body appearing of that colour of which the light coming from it is most composed."

To produce white light, it is necessary there should be a reunion of all the colours, for if either be intercepted the white is not produced, and we may, in fact, form any shade of colour, with a brilliancy surpassing any artificial colouring, by modifying the amount of the several rays.

Dr. Wollaston considered the spectrum to consist of only four colours, red, green, blue, and violet, supposing the others to be compounded of them. Dr. Young on the other hand, considers red, green, and violet as the fundamental colours.

From what has been said, it will almost suggest itself to every mind, that the colours of bodies are not inherent. We have seen the same white screen presenting a red, yellow, violet, and other colour according to the character of the ray, or combination of rays thrown upon it. The real cause of a variety of colour, according to the Newtonian theory, is the different dispositions of substances to reflect peculiar tints. Every substance has a greater power to reflect one coloured

ray than another, and the others are more or less transmitted, stifled, or in other words absorbed. This is the Newtonian theory of colours, and is supported by the ready explanation it gives to every phenomenon.

DISPERSION.

In explaining the laws of refraction, the refractive index of a ray incident upon a medium, was considered as though it passed through in one direction, and suffered no separation. It must now be evident, that this is not absolutely true; for in passing through a refracting medium, the ray does undergo separation, is divided into a number of parts, and is in fact dispersed over an angle greater or less, according to the nature of the medium on which it falls, and the obliquity of the incident ray.

The first proposition in Sir Isaac Newton's Optics, is, "Lights which differ in colour, differ also in degrees of refrangibility." This he proved by some interesting experiments. In his first experiment he took a piece of oblong paper, which he cut so as to form the sides parallel. He then drew a perpendicular right line from one side to the other, so as to divide it into two equal parts. One of these he painted red, the other blue. This paper he viewed by means of a glass prism, "whose two sides through which the light passed to the eye were" says Sir Isaac, "plane and well polished, and containing an angle of about 60°, which angle I call the refracting angle of the prisms; and whilst I viewed it,

I held it before a window in such a manner that the sides of the paper were parallel to the prism, and both those sides and the prism parallel to the horizon, and the cross line perpendicular to it; and that the light which fell from the window upon the paper, made an angle with the paper equal to that angle which was made with the same paper by the light reflected from the eye." He then observed that when the refracting angle of the prism was turned upwards, the blue half was raised by refraction higher than the red, and when the refracting angle of the prism was turned downwards the blue half was depressed lower than the red."

From this it was proved that blue colour suffers a greater degree of refraction than red.

A question naturally presenting itself in this place would be, Do media differ in their dispersive powers? Different media have different refractive powers, have they different dispersive powers? Newton supposed that they had not, and Mr. Hall of Worcestershire was the first to discover the mistake. But his discovery, though applied by himself to the construction of achromatic telescopes, appears to have been neglected. It was re-discovered and re-applied by Mr. Dollond.

If we take two prisms, one of flint glass, the other of crown, having equal refracting angles, and let two rays fall upon them severally, both rays will be decomposed, but upon comparing the spectra several points of distinction will be observed.

The deviation of the red and violet rays, as produced by the flint glass, will be greater than that produced by the crown; and the angles of dispersion will not be to each other in the

same ratio with the angles of deviation, as Newton supposed them to be, but in a higher ratio.

But now let us take a prism of crown glass, with a refracting angle so much increased, as to make the deviation of its red ray equal to that of the flint; the violet ray will not, even now, be of equal deviation with that of the flint glass prism. If, therefore, we take two such prisms, and place them together with their edges turned opposite ways, the red ray will be equally refracted in opposite directions, and will suffer no deviation, but as the violet ray is more refracted by the flint than the crown, it will be bent downwards towards the thicker part of the glass, and an uncorrected colour will remain. By this means we may determine the dispersive powers of different media.

From what has been already stated, it will appear a most desirable object to correct the dispersive power of any medium; and in order to do this, we must first determine the amount of its dispersion. How is this to be done? Let us suppose that we have formed the substance whose dispersive power is required into a prism, that we have ascertained its refracting angle, and refractive index. Now, if we would determine its dispersive power, we must have some standard of measurement. It is certainly impossible for us to have a series of standard prisms of every refracting angle required, we must, therefore, have some means of varying the refracting angle of the same prism, and thus we shall obtain a standard. Several methods of doing this have been proposed.

This subject has more than a speculative interest, for in its

application to the improvement of the refracting telescope, it has the greatest practical utility. It may be taken as an axiom that refraction cannot happen, without the production of colour, for every lens acts in the same way as a prism. When, therefore, we combine lenses in a telescope, we can only destroy colour by the destruction of the refractive power; as when, in a previous experiment, we combined two prisms of the same materials and exactly the same dimensions. But by the union of lenses having different dispersive powers, this may be done; for lenses have been constructed which do refract without producing colour. These are called achromatic, from two Greek words signifying without colour.

ABSORPTION OF LIGHT.

It has, perhaps, been often asked, why are some bodies transparent, and others opaque? Although we cannot give a direct answer to this question, we may illustrate the cause of the phenomenon. When we say that a body is transparent, we mean that it will allow light to pass freely through it, which may be an actual passage through the molecules or between them. But no body is perfectly transparent, for a portion of light is always lost in passing through a medium. This must often have been observed when light is admitted first through an opening, and then through glass. It is also well known, that on the tops of high mountains a greater number of stars can be seen by the naked eye, than on the plains, which must be occasioned by the absorption

of light during its passage to the earth, through the lower portions of the atmosphere.

And as no body is perfectly transparent, all are transparent in a degree. Gold, a dense metal, may be beaten so thin as to admit the passage of light; and charcoal, the most opaque of all bodies, is one of the most transparent in the condition of a diamond.

This diminution in the intensity of light, in passing through media, is called absorption. But every substance is unequally transparent for the differently coloured rays, some are always absorbed in preference to others, and this causes the colours of bodies as seen by transmitted light. Sir John Herschel mentions an interesting experiment, by which it may be shown that even the same substance has different absorbing powers on differently coloured rays. Take a piece of deep blue glass and look through it at the image of a narrow line of light, as a crack in the shutter of a darkened room, refracted through a prism, "whose edge is parallel to the line and placed in its situation of minimum deviation." If the glass be thin, the whole of the spectrum will be seen; if of moderate thickness it will be separated by perfectly black intervals, which correspond to the extinguished rays. Increase the thickness, and the black spaces become broader and broader.

The hypothesis proposed to account for this phenomenon may be thus explained. It is supposed, that for every equal thickness of the medium traversed by the light, an aliquot part of the rays is absorbed. Let us suppose that one thousand rays fall on a green glass, and that in travers-

ing the first one-tenth of an inch, one hundred are extinguished, there will then remain nine hundred at that point; one-tenth of these will be absorbed in passing through the next one-tenth of an inch, and so on. According to this theory, total extinction cannot happen in any medium of finite thickness, but it may be reduced to an inappreciable quantity.

It must have been often observed, that the same medium will present different colours when it has different thicknesses, and this may at first appear altogether unaccountable by the hypothesis. We will, however, give a condensed account of Sir John Herschel's illustration. Let us take a thin hollow glass wedge, and enclose in it a strong solution of muriate of chromium. "If we look through the edge where it is thinnest, at white paper, it appears of a fine green, but if we slide the wedge before the eye gradually so as to look successively through a greater and greater thickness of the liquid, the green tint grows livid, and passes through a sort of neutral brownish hue to a deep blood red. The green liquids in question have two distinct maxima, the one corresponding to the extreme red, the other to the green." But the extreme red is very feeble compared with the green, and does not at first affect the eye, but as the absorption goes on, the green rays are more rapidly extinguished, and the red rays gradually become more distinct, and overpower the green. Let us, for instance, suppose that a beam of white light is incident on this prism of muriate of chromium, and that the beam is composed of ten thousand rays, *all equally illuminative;* then, according to the pro-

portions existing between the colours, we should have the following results, in which green has the superiority until passing through the fifth one-tenth of an inch, and then the red predominates.

	Extreme Red.	Red & Orange.	Yellow.	Green.	Blue.	Indigo.	Violet
Proportion of 10,000 rays	200	1300	3000	2800	1200	1000	500
Proportion after passing							
1-10th of an inch	180	130	300	1400	120	100	50
" 2d 1-10th "	162	13	30	700	12	10	5
" 3d 1-10th "	146	1	3	350	1	1	0
" 4th 1-10th "	131	0	0	175	0	0	0
" 5th 1-10th "	118	0	0	87	0	0	0
" 6th 1-10th "	106	0	0	43	0	0	0

This explanation may be applied to all those cases where the colour of transmitted light changes with the thickness of the plate. A great number of instances will probably suggest themselves; one of the most common occurrence is that in which the absorption increases from the red to the violet end. Red glasses, port wine, infusion of saffron and other substances, act very rapidly on the violet rays, and soon entirely obliterate them.

THE ANATOMY OF THE EYE.

No part of the human body is more refined in operation, or more delicate in construction, than the eye. It is an organ consisting of an assemblage of lenses, so arranged, as to concentrate all the rays falling upon it from different objects, and to project their images upon a nervous expansion called the retina. For the convenience of description anatomists

are accustomed to explain the construction of this organ under the two general divisions,—the bulb of the eye, and its appendages.

The eye-lids or palpebræ, are the most prominent appendages of the eye. "The eye-lids, or moveable curtains suspended before the eye are," says Mr. Dalrymple, in his most excellent work on the anatomy of that organ, "composed of skin, cartilage, ligament, muscles, mucous membrane, glands, hairs, and a peculiar cellular tissue. Simple as they may appear, if viewed externally, and without reference to their physiological arrangement, still there is no little complexity in their minute organization; and upon the nice adaptation and close correspondence of each lid with the other, and both with the eye-ball, depends not only the perfection of vision, but also the actual safety of the organ. The palpebræ are lined with a soft substance, which, connecting the eye and the lid, has received the name of tunica conjunctiva."

The uses of that structure usually called the white of the eye, are to prevent friction between the eye and its lid, and at the same time to defend the globe from dust, insects, and other small substances contained in the atmosphere. The skin is remarkably thin and delicate. Shakspeare refers to the beautiful structure of this apparatus in the following description,—

> "The flame o' the taper
> Bows towards her, and would underpeep her lids,
> To see the enclosed lights, now canopied
> Under these windows: white and azure, laced
> With blue of heaven's own tint."—*Cymbeline.*

The borders of the eye-lids are ornamented with a row of stiff hairs, called cilia, or the eye-lashes, which are necessary for defence as well as for beauty.

The two extremities, or corners of the eye, are called canthi; that near the nose is the canthus major, and the other the canthus minor.

Towards the upper part of the eye is the lachrymal gland, which furnishes the fluid called tears. To favour the escape of this fluid there is a small hole in each eye-lid, called the punctum lachrymale, near which is a little fleshy substance, the caruncula lachrymalis, which, by preventing the eye-lids towards the canthus major from closing entirely, partly answers the end of the puncta lachrymalia. The gland is powerfully acted upon by mental excitement, and its secretion is often so great as to flow over the cheeks instead of passing through the aperture provided for it.

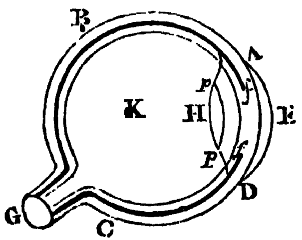
"The lachrymal apparatus," says the author already quoted, "may be divided into two distinct portions; one secreting, the other distributing and conveying away the fluid furnished. The former of these, consisting of the gland and its ducts, is situated at the upper and outer part of the orbit. It is wholly distinct from and independent of the latter, which is placed principally at the inner angle of the eye. The tears must, therefore, pass from without inwards, over the anterior surface of the sclerotic and corneal membranes, before they are finally conveyed through the lachrymal puncta and canals into the nasal cavities."

These are the appurtenances of the eye, and we now proceed to explain the structure of the organ itself, which is

extremely beautiful from its simplicity as well as its adaptation to the purposes for which it was formed.

The eye-ball is nearly spherical and about an inch in diameter. ABCD, fig. 43, is the exterior coat enclosing all the membranes and humours, and is called the tunica sclerotica. It is a tough, opaque membrane, and derives its name from a Greek word, expressive of its peculiar structure.

Fig. 43.



A small round portion AED of this exterior coat, differs in character from the other parts; it is called the cornea, and is situated in the centre of the eye, and is so tough that it will resist any moderate external force. Its real figure, according to M. Chossat, is an ellipsoid of revolution round the major axis.

The aqueous humour is situated immediately behind the cornea, and filling up the cavity gives a spherical appearance to that part of the eye. It consists of water holding a little muriate of soda and gelatine in solution, with a trace of albumen. Its refractive index according to the experiments of Dr. Brewster is 1·337, almost exactly the same as water. The iris, *ff*, which is situated within the aqueous humour, is an opaque circular membrane, or collection of muscular fibres, having an aperture in the centre, called the pupil. This aperture may, by a beautiful muscular arrangement, be contracted or dilated, so as to be adapted to the intensity of light falling upon it. When the light is strong the pupil is

contracted; when feeble dilated. Behind the iris there is a transparent lens *p p*, called the crystalline lens. It contains in its composition a much larger proportion of albumen and gelatine than any of the humours of the eye, and is somewhat denser towards the centre, than at the outer surface. This increase of density is evidently important in correcting the aberration, which is probably its entire use. The vitreous humour K fills up the remainder of the eye. It differs but little in composition from the aqueous humour, and is probably intended to preserve a fitting distance between the lens and the retina.

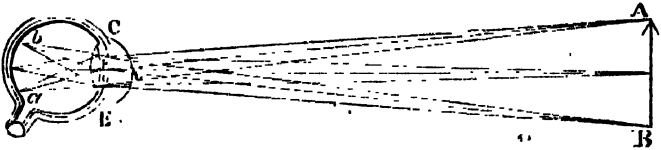
We have spoken of the sclerotica as a membrane enclosing all the coats and humours of the eye. Now the inner surface of the posterior part of this coat is covered by a delicate membrane, called the choroid, which is lined with a black velvety matter, the pigmentum nigrum, evidently intended to absorb and stifle all the light which reaches it. On the inner side of this lies the retina, which lines the whole of the posterior chamber, to the point where the capsule of the lens commences. The retina is a fine delicate membrane, an expansion of the optic nerve, which connects the eye with the brain, and joins with it near the inner corner of the eye. Upon the retina the image of objects are painted, and by it conveyed so as to produce sensation. The situation of the pigmentum nigrum immediately behind it, is, therefore, most admirable, preventing any confusion of vision that might arise from internal reflexions.

Such is the structure by which the rays of light are converged and brought to a focus on the retina. But we are

able to see objects situated at various distances, those which are near, as well as those which are distant. There must then be some internal power by which the eye can adapt itself to the different situations of objects. The focus of a lens or system of lenses is longer for near than for distant objects, and as the eye is only a system of lenses, there must be some power of adjustment. We do, in fact, know, that there is such a power, for we feel pained by any continued exertion of it, and hence we are led to suppose it a muscular action, but anatomists and philosophers are undecided as to its nature. Dr. Olbers, Sir Everard Home, and Ramsden attribute it to the action of the recti muscles, which are used to move the eye in its orbit. By the simultaneous action of these it is said a pressure is exerted upon the fluids, forcing out the cornea, and increasing its distance from the retina. But Dr. Young objected to this explanation, and has, we think, satisfactorily proved that the cause assigned cannot be the true one. He also shows that in order to give distinct vision at a distance of three inches the eye must be forced into the form of an ellipsoid, having its axis one-seventh longer than in its natural state. This seems in itself improbable, and particularly so when we consider the extreme toughness of the sclerotica. Dr. Young is rather inclined to suppose that the crystalline lens is capable of an alteration in form, and becomes more convex when the eye is to be adapted to a near distance. This opinion is strengthened by the muscular appearance of the lens, as may be seen by the examination of the eye of a fish. Nerves have not yet, it is true, been traced, but there is at least a strong presump-

tion that this is the mechanism adopted, the subject however is fully open to examination.

Fig. 44.



The influence of the several humours upon the direction of the rays may be easily traced:—Let A B, fig. 44, represent an object at a considerable distance from the eye C E, and B *b*, A *a*, rays of light proceeding from it. The action of all the humours is to converge the pencils of light, and so much so that the rays cross, and the image is painted on the retina in an inverted position; the rays A will fall upon it at *a*, the rays B at *b*. The image of an object being inverted on the retina, it may be considered as not a little singular that we perceive every thing upright. This has been denied by some authors, who believe that we perceive all objects inverted, and that the sense of touch corrects the errors of sight.

The case of the Boy found at the gates of Luxemburgh, who had from infancy been confined in a dark chamber, is one of many examples, that when sight is first given objects are not seen in an inverted position. There is, therefore, some agency, unknown as yet to the anatomist and philosopher, between the retina and the brain, or between the animal and thinking beings, which effects this change.

Defective vision or total blindness may arise from a variety

of causes. Any affection of the optic nerve will of course have a direct influence; paralysis for instance may produce while it lasts, total blindness, and cases have been known where the affection of one nerve has caused half blindness. The loss of transparency in the crystalline lens, as in cataract, preventing the passage of light will produce an indistinct vision or blindness. But by removing or putting out of the way an opaque crystalline, the perception of light is restored, but as the natural medium of convergence is destroyed, an artificial one will be required, or the image will be formed beyond, instead of on the retina. Hence it is that those who have undergone the operation for cataract, require glasses. A convex lens has the property of converging rays, and must, therefore, be used. Aged persons also require the same kind of glass, for the crystalline becomes flatter, and an imperfect image is formed on the retina.

Short-sightedness is produced by the too great convexity of the lens, and suitable concave lenses are required, to throw the images of objects on the retina, which naturally in such cases fall short of it.

APPEARANCES OF OBJECTS AFTER REFRACTION AND REFLEXION.

The attention of modern philosophers has been much directed to the invention and improvement of optical instruments, and great has been their success. But before we proceed to speak of the various instruments dependent on opti-

cal principles, and to describe their construction, it will be necessary to refer to the appearances presented by objects after refraction and reflexion. We have already explained the most important laws of reflexion and refraction, but we have not as yet referred to the appearances under which bodies are seen after their images have been transmitted through, or reflected from plane, convex, and concave surfaces. This we shall now attempt, and shall then be prepared to estimate the effect of optical instruments.

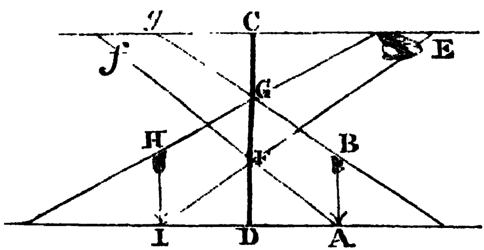
We may first direct attention to the effects of reflexion from mirrors. Mirrors are metallic substances polished on their anterior surface, or plates of glass silvered on their posterior surface, and capable of reflecting the light from any body before them, and of presenting an enlarged or minified image. They may be divided into four classes, plane, concave, convex, and cylindrical, but the reflexion of light from all these obey the same law, that is, the angle of incidence is always equal to the angle of reflexion.

PLANE MIRRORS.

When an object is viewed in a plane mirror, it always appears to be at the same distance behind the mirror as the object is before it. This illusion is so powerful that when an animal views himself for the first time in a looking glass, he will almost for certain imagine the image to be another animal of his own species. Birds are extremely susceptible of this, and a cock will immediately prepare himself for combat, and

if the glass be not removed, will speedily demolish the cause of his wrath. The fury which this pugilistic bird always displays is uncommonly entertaining. It will not be difficult to explain the cause of this illusion. But it may be necessary to premise a fact, to which we have already referred, that an object is always seen in the direction of the ray when it strikes the eye, whatever may be the position of the luminous body.

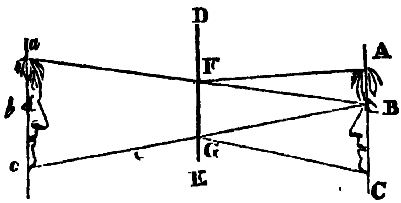
Fig. 45.



Let A B, fig. 45, be any object, and A F, B G, rays proceeding from it, which would move on beyond the points f and g, if there were no reflecting surface, but the mirror C D intervenes and reflects them into the direction F E, G E, where the eye receives the impression of the object. But E F, E G, being the direction of the rays when they meet the eye, the image will be seen in that direction, and the points I H will appear as far behind the mirror as A B is before it.

From this it necessarily follows, that objects viewed in a plane mirror can only appear half their true size. Let A B C, fig. 46, be the head of a man viewing himself in a glass D E. The image will, as we have just now stated, appear to be as

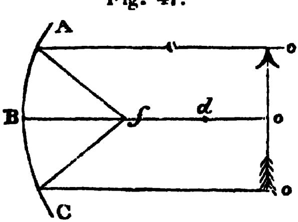
Fig. 46.



far behind the mirror, as the man is before it. The mirror must, therefore, bisect the cone formed by the converging rays, and hence F G, can only be half A C. The length of an image cannot, therefore, be more than half the length of the object, and the same is true of the breadth, and all other dimensions. This may be practically proved by measuring the image and the object, or by looking in a glass which is only half the dimensions of the face. It has probably been noticed by the reader, that when two mirrors are arranged parallel to each other, with their faces opposite, the object being placed at one extremity the eye at the other, that the object will appear infinitely multiplied. This is the result of reiterated reflexion from one surface to another, and the images gradually become more indistinct as their distance increases.

CONCAVE AND OTHER MIRRORS.

Fig. 47.



Concave Mirrors may be considered, as already stated, to consist of an indefinite number of small planes, which make a determined angle with each other, so as to throw all the rays into a point. Let A B C,

fig. 47, be a concave mirror, and let *d* be the centre of curvature, and let *o o o* be rays of light falling from a body on the mirror. These rays will be reflected and meet in a point *f*, called the focus, where an image of the object is formed in an inverted position. When the curvature is not very great, the distance of the focal point from the surface of the mirror is half its radius.

Concave mirrors are frequently used for the collection of the solar rays into a point for the production of intense heat. A mirror constructed by M. de Villette possessed this property in a most remarkable degree. The diameter of this spectrum was four feet eleven inches, and was composed of tin and copper highly polished. When exposed to the rays of the sun, a silver sixpence placed in its focus, was melted in seven seconds and a half; a copper halfpenny melted in sixteen seconds, and liquified in thirty-four seconds.

If any one looks into a large concave mirror, its distance from him being greater than its focal distance, there will appear between himself and the mirror, a minified representation of his own form suspended in the air, but inverted. This deception is very strong, and if the object itself were inverted, an ignorant observer would with difficulty be brought to believe that the image was not tangible. There has been considerable suspicion that this experiment was made on a large scale by Pagan priests, in the caves of Trophonius, the temples of Delphi, and other places where mysteries were common. Esculapius was often seen by his worshippers at his temple at Tarsus, and the goddess frequently appeared in the temple of Enguinum. It is also to be feared that the

ministers of a purer religion have in past times used the same instrument as an engine of superstition. It was commonly believed by the lower classes, that Friar Bacon had walked in the air from one church steeple to another, although the more educated were aware that the appearance was produced by a reflected image of his person upon the clouds as he walked upon the ground. This statement is made upon the authority of Lord Bacon. The same trick is exhibited by modern conjurors, and that very effectually, by the means which they take to exclude from sight both the mirror and the object.

Convex mirrors give to objects an erect but diminished image, which appears to emanate from behind the mirror, in fact from the focus. They are chiefly used as ornaments in apartments.

Cylindrical mirrors are not used in the construction of optical instruments, but are ground by opticians for the purposes of amusement. When any one views himself in one of these, if the direction of the axis of its concavity be perpendicular to the horizon, his visage will be uncommonly distorted; diminished in breadth, but in length continuing as usual. The drollery of the figure will strongly remind the observer of Homer's description of Thersites. Upon turning the mirror a quadrant, the opposite extreme takes place; the image much resembling a piece of paper with two lines drawn on it, one in black ink, the other in red. The eyes are elongated so as to resemble the black line, and the lips the red; added to this the extraordinary breadth of countenance, and the ungovernable obstinacy of the image is very

laughable for, however wide the mouth may be opened, the figure pertinaciously keeps his shut, and only a white stroke of extreme tenuity is seen, parallel to the red one, which is produced by the teeth. If the mirror be held close to the face of the observer, its axis being vertical, and the finger be put to the side of the nose, the image will of course do the same. But when the mirror is removed to a greater distance from the face, and the finger is again placed on the right side of the nose, the image will place his on the left. "I could contain no longer," says an author, after making this experiment, "but gave vent to my inclination by a loud fit of laughter. Unhappy being! for now the image opened his mouth to such an astonishing extent, and his long countenance seemed so dreadfully convulsed with some uncommon passion, that I willingly let the mirror fall to the ground, avowing that I would never look into another."

Anamorphoses are frequently used with these mirrors. They are pictures drawn in so distorted a shape that they cannot be said to possess any determinate form, but they are rectified when presented to the mirror, and reflect an image of some natural object.

Mirrors of variable curvature are also used for amusement, and although they never produce a decided caricature, they variably distort the object according to its distances and positions.

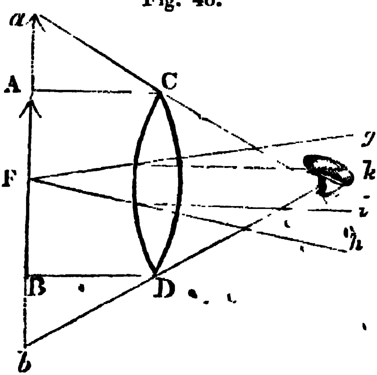
LENSES.

We must now pass on to briefly notice the appearances presented by bodies after refraction. It has been already

stated that light is converged or diverged by refraction according to the form of the surface through which it has to pass. When a transparent substance is formed into a shape adapted to collect the rays of light, it is called a lens. There may be said to be four classes of lenses; the convex, the concave, the meniscus, so called from its resemblance to the horned appearances of the moon, when a few days old, and the crossed lens, which has unequally curved convex surfaces.

When light passes through a convex lens, whether both or only one surface be convex, the rays are converged into a point, called the focus. An object viewed through a convex lens appears larger, and brighter than without the intervention of that medium. Let A C and B D, fig. 48, be two rays incident upon the lens, and by it refracted to the eye. The apparent path of these is referred by the eye to *a* and *b* upon the principle that the position of an object is always seen in that direction in which the ray meets the eye: hence the object is magnified.

Fig. 48.



But the object is also brighter, for let us imagine two diverging rays to emanate from F, if the lens did not intervene, they would pass to *g* and *h*, never reaching the eye;

but the lens converges them and brings them to the points *k* and *i*, within the range of vision.

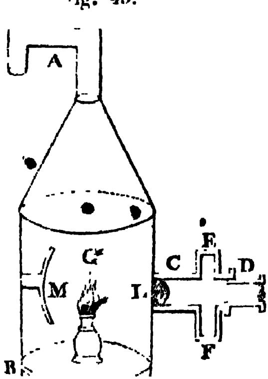
Convex lenses have been employed as burning glasses, the largest was made by Mr. Parker, and was three feet in diameter. It had a power sufficient to fuse twenty grains of pure gold in four seconds and ten grains of platina in three seconds.

Concave lenses cause the rays of light to diverge, and all objects viewed through them appear nearer, smaller, and less bright than they were before their interposition. Objects are multiplied when viewed through a medium, which has several surfaces.

OPTICAL INSTRUMENTS.

MAGIC LANTERN.

Fig. 49.



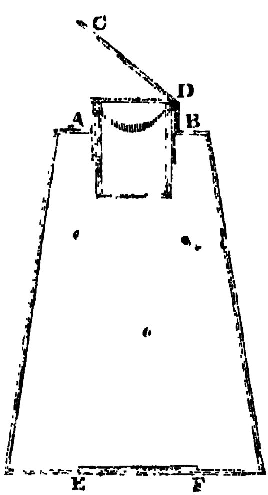
The Magic Lantern was invented in the seventeenth century, and is among the simplest of optical instruments. It consists of a dark lantern A B, fig. 49, containing a lamp G, in front of a concave metallic mirror M. C D is a double tube fitted into the front of the lantern, the outer portion D, moving in the other. At the posterior end of the double tube

is fixed a large plano-convex lens, and at the other end a small double convex lens. E F is a groove made in the larger tube in which the sliders having the objects painted on them, are placed. The light of the lamp is thrown on and reflected from the mirror M to the lens L, by which it is concentred falling upon the slider. This slider or in other words the painted object, being arranged to the conjugate focus of the lens L, a magnified image will be formed on the screen.

The magic lantern has been rendered much more effectual by the use of figures painted on opaque grounds.

THE CAMERA OBSCURA, OR DARK CHAMBER.

Fig. 50.



This is an instrument invented by Baptista Porta. A B, fig. 50, is a meniscus with its concave surface uppermost; D C is a plane metallic reflector inclined to the horizon at an angle of 45°. The landscape is thus reflected downwards through the lens, and is painted on the paper at E F. In one side an opening is made and through this the artist introduces his head, and through another his hand.

REFRACTING TELESCOPES.

A telescope is an instrument employed to view distant objects, and it assists us in examining them by increasing the apparent angle under which they are seen with the naked eye. It was invented about the year 1590, by whom is uncertain, some say John Baptista Porta, some Galileo, and others Jansen of Middleburgh. Some persons attribute the discovery to the children of Lippersheim, a spectacle maker at Middleburgh, and Borellus in his De Vero Telescopii Inventore attributes the discovery to Joannides.

Telescopes are of two kinds, refracting and reflecting, and of each there are several varieties. The first telescope that Galileo made magnified only three times, and that with which he discovered the satellites of Jupiter thirty-three times. We shall first speak of refracting telescopes, and the simplest construction of this instrument, is that called the Galilean. It has only two lenses, and these are placed at a distance from each other, equal to the sum of their foci. Let the object lens have a focus of eight inches, and the eye lens a focus of two inches; then the distance between these two glasses must be ten inches, more or less, according to the distance of the object, or the vision of the individual. This instrument is not suited for observations on land, for it inverts objects. It is occasionally used at sea, at night, when from the small intensity it becomes necessary to prevent the absorption of light by its passing through a

number of lenses: it is hence called a night telescope. The astronomical refracting telescope is made upon the same principle, for the inversion of the object is here of no importance. There is, however, a great hindrance to the extensive use of this instrument, for when high powers are employed the image becomes indistinct, and if the dimension of the object glass be increased, the telescope itself is increased in length, and becomes unwieldy. M. Huygens, however, made one of immense size, the focus of the object glass being one hundred and twenty-three feet, and even with this length he could only have a six inch aperture.

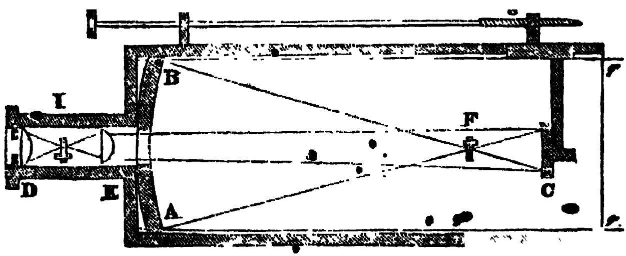
The common day telescope differs from the night, in having two extra lenses of the same form and size as the eye glass, and these are *fixed* at a distance from each other equal to the sum of their foci. Thus let us take the same lengths as we did in the former case, let the focus of the object glass be eight inches, of the eye glass two; then the two extra lenses will have foci of two inches each: they must, therefore, be fixed four inches apart; the object glass will be ten inches from the one, the eye glass four inches from the other. The purpose of these two lenses is the erection of the image.

The great length of refracting telescopes when applied to astronomical purposes renders them very inconvenient, and the attention of philosophers was consequently drawn to the enquiry, whether a reflecting telescope could not be invented.

REFLECTING TELESCOPES.

There are three kinds of reflecting telescopes, distinguished by the names of their inventors. The Gregorian telescope was invented by Mr. James Gregory, when a student at Glasgow. From the slighting manner in which some writers speak of Gregory's claim to the honour of his discovery, it would seem that even at the present day there are some persons who cannot help feeling jealous at his great philosophical talent. But although this instrument was invented six years before the Newtonian, it was not constructed for some years after Newton had completed his six inch reflector.

Fig. 51.

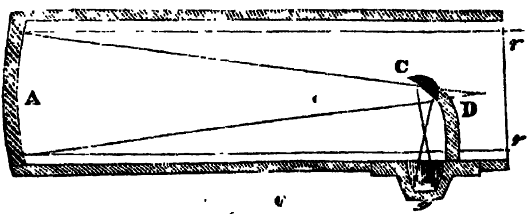


The construction of the Gregorian telescope is very simple. A B, fig. 51, is a concave mirror formed by the revolution of a hyperbolic curve, and in the centre is a small aperture: C is a concave elliptical mirror, placed in the axis of the larger at a distance from it, of little more than their focal distances, and adjusted by the screw *s*. D and E are the

eye lenses. Let the rays *r r* emanating from any object fall upon the spectrum A B, from it they are reflected converging and crossing each other at F form an inverted image upon the small mirror C. From this they are reflected converging, and pass through the lenses by which the image is conveyed to the eye.

The Newtonian telescope is seldom made less than five feet in length. It consists of a parabolic speculum, from which the rays are reflected as in the Gregorian telescope, and are in the same manner intercepted by a smaller mirror, but in this case it has a plane surface, and is fixed so as to form an angle of 45° with the axis of the tube, throwing the rays towards the side.

Fig. 52.



A section of the Newtonian telescope is shewn in fig. 52. A is a concave parabolic mirror; C is a plane mirror fixed to the arm D, which is connected with the eye piece *g*. This is usually made to slide upon the tube, but would be more readily adjusted if made to move by a screw in the same manner as the Gregorian telescope. The eye glass is a plano-convex lens with its flat side outermost, and is called the astronomical eye-piece. On account of the colour produced by these lenses the negative achromatic eye lens is

generally added. Dr. Brewster has recommended the use of two glass prisms instead of the eye glass.

This telescope has been much improved since its invention, but the most important alteration was made by Sir Isaac himself. The first one was made with a large spherical concave mirror, but he afterwards discovered that the spherical aberration might be destroyed by giving it a parabolic form.

Herschel's telescope, sometimes called the front view reflector, is only used when a very large field is required. It has no small mirror, and the image is viewed in the focus of the great mirror with an eye glass. This arrangement has many advantages over other reflectors, especially in preventing the loss of light by frequent reflexion and refraction. The largest instrument of this kind in the country is at the Royal Observatory.

MICROSCOPES.

Notwithstanding the great varieties of form in which we are accustomed to see the microscope, they may all be divided into three classes. The single, the compound refracting, and the compound reflecting.

It must have been observed by every one, that the more distant an object is from us, the less it appears, and hence the purpose of the microscope is to produce this effect. If we have to examine a very small object, we bring it near the eye, but at less than a certain distance, it becomes indistinct

and confused, which is caused by the divergence of the rays of light from the object, and the incapacity of the crystalline lens to collect the rays ; but if we use a convex lens, placing it between the object and the eye, the divergence is corrected, and the rays are collected by the crystalline lens.

These are fitted up in various ways, and are called Mineralogical, Botanical, or Anatomical Microscopes, according to the purpose to which they are to be applied.

Small spheres have often been used for single microscopes. A globule of glass melted in the flame of a spirit lamp, is admirably adapted for the purpose. Mr. Stephen Gray made globules for microscopes by inserting drops of water in small apertures. Dr. Brewster has used the crystalline lens of small fish, such as the minnow, taking care that the axis of the lens is the axis of vision, in other words that you look through it in the same direction as the fish had done before you. The garnet, the ruby, and the diamond have also been employed for the same purpose with very great success.

Compound Microscopes are those which consist of two or more lenses, one of which forms an enlarged image of objects, while the others magnify it. The compound refracting microscopes, though susceptible of considerable accuracy, are much less commonly used than either of the other class.

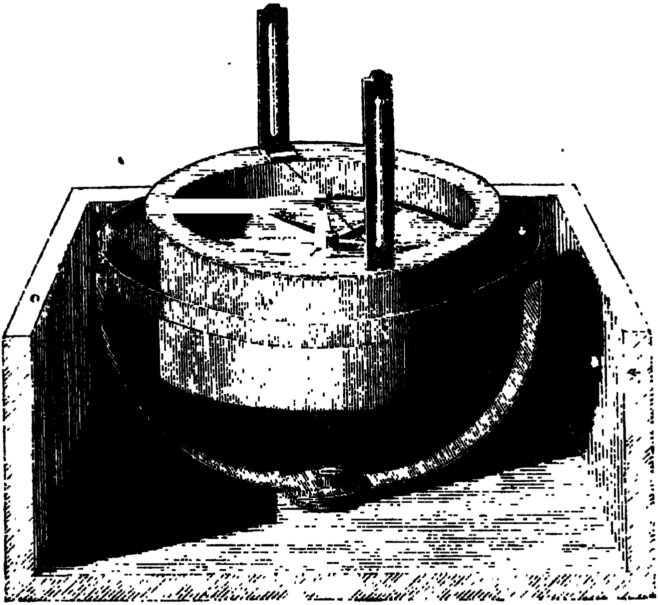
The simplest of all reflecting microscopes is a concave mirror, in which the face of an observer is always magnified, and when we view the figure with a lens instead of the eye, we have a compound reflecting microscope. And this

is but the instrument proposed by Sir Isaac Newton, and afterwards improved by Professor Amici of Modena.

CONCLUDING REMARKS.

The science of which we have been speaking, is one of the most interesting branches of modern investigation, and to detail in a condensed form the facts which have been discovered, would require a larger volume than that we are now presenting to the public. A few pages only could be devoted to it, and the author's chief difficulty was to select those facts and principles, which are most important to him who is commencing his philosophical inquiries. Many subjects have been entirely omitted; such as inflexion, the colours of thick and thin plates, and that absorbing but difficult branch of the science, the Polarization of Light.

None of our readers, however, will imagine that we pretend to give a full, much less a minute account of the physical sciences; the elementary facts alone come under our consideration, since we write for those who are beginning to learn, and not for those who have made some progress.



THE MARINER'S COMPASS.

CHAPTER VI.

MAGNETISM.

DIRECTIVE FORCE OF THE MAGNET.

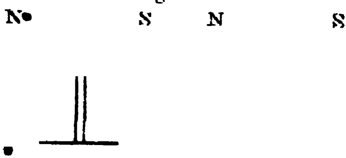
It has long been known that an ore of iron, chiefly consisting of an oxide of that metal with a small proportion of quartz and alumina, has the remarkable property of a directive force. This ore is called the native magnet or loadstone. When freely suspended on its centre of gravity so

as to have a capability of turning in any direction, one end will always, when it comes to rest, point to the north pole of the earth, the other to the south.

But the loadstone not only possesses in itself this singular directive force, but can also communicate the same property to other ferruginous substances. The manner in which this is done we shall explain in an after part of this chapter, it is only necessary on the present occasion to refer to the fact because we are able, by the use of artificial magnets, to accommodate ourselves with magnets formed in shapes more convenient for experiment, than those which are found in their natural state.

But magnets are possessed of another singular property, which must be mentioned in this place for the better understanding of their directive property. The pole of a magnet will always repel that pole of another magnet, which has the same name. Thus, if we suspend two magnets, fig. 53, in such a manner that they may have perfect freedom of motion, and bring their north or south poles together, they will repel each other; but if a north pole be presented to a south pole, then an attractive force will be exhibited. When we speak of the poles of a magnet, we mean those points where the directive power is concentrated, which in bar magnets is usually at the ends, that end which points to the north, being called the north pole, that to the south the south pole. But although the magnetic power is

Fig. 53.



strongest at these points, it is not confined to them. The whole of a magnet possesses the magnetic power, but the force decreases towards the centre, and is there at its minimum. This may be proved by bringing one bar magnet successively to every part of another, and it will then be found that at the center the power is almost lost. It may also be approximately shown by surrounding a bar magnet with iron filings, for the magnet attracts them variably, the largest quantity surrounding the poles, the least at the centre. But still it is a singular fact, and not we think satisfactorily accounted for, that if a magnet be broken at the centre, one half will not be found to possess a north direction, and the other half a south, but each will be a perfect magnet, having a north and south pole.

MAGNETISM OF METALS.

It was long supposed that iron was the only substance capable of possessing the magnetic power, but philosophers are now aware that nickel receives and retains magnetism though in a very inferior degree to steel.

Dr. Faraday recently performed a series of experiments[1] to determine whether any other metals besides iron and nickel could be made to exhibit magnetic properties. When he commenced his inquiries he had but little doubt that all metals were magnetic, though not at common temperatures; he imagined that every metal was magnetic beneath a certain

[1] Philosophical Mag. Third Series, vol. viii. p. 177.

temperature, and lost the[1] property when raised above it. Mr. Barlow had proved that iron loses its magnetic properties, at an orange heat, so entirely, that it does not even intercept the attractive influence between a magnet and a bar of iron. From a consideration of this fact, Dr. Faraday was led to imagine that there might be a temperature below that to which substances are commonly exposed on the surface of the earth, at which those metals supposed to be destitute of magnetism might exhibit its ordinary phenomena.

Pieces of metal in their pure state were supported on very fine platinum wires, and being cooled down to a temperature of from 60° to 70° Fahrenheit below zero, were brought close to one end of the needles of a delicate astatic arrangement, and the magnetic state was judged of by the absence or presence of an attractive force. The following metals were examined:—

Arsenic	
Antimony	Lead
Bismuth	Mercury
Cadmium	Palladium
Cobalt	Platinum
Chromium	Silver
Copper	Tin
Gold	Zinc

and plumbago; but none of these evinced the slightest degree of magnetism. Whenever cobalt or chromium, which are supposed to be magnetic metals, gave indications of magnetic

[1] Phil. Trans. 1822, p. 117.

properties, iron or nickel was always detected. "The step which we can make downwards in temperature, is, however," says Dr. Faraday, "so small as compared to the changes we can produce in the opposite direction, that negative results of the kind here stated, could scarcely be allowed to have much weight in deciding the question under examination, although unfortunately, they cut off all but two metals from actual comparison." Still the Doctor seems to be of opinion that all metals may be reduced to a temperature beneath which they are magnetic. The de-magnetizing temperature for nickel was found to be about 630° or 640°.

The same philosopher made some experiments to ascertain the relation between the temperature which destroys the polarity of a magnet, and that which takes from soft iron or steel, the property by which it acts on the magnet itself. At about the temperature of boiling almond oil, magnets suddenly lost their polarity, and then acted on a magnet as soft iron; and when raised to a full orange heat, they lost their power as soft iron. The natural magnet or loadstone was found to retain its polarity, at a higher temperature than the artificial steel magnet, for the polarity was not lost till it was brought to the temperature of a dull ignition.

DIRECTIVE FORCE.

Having premised these facts, we shall now be prepared to inquire more particularly into the phenomena and nature of the directive force. It has been stated that if a needle be

suspended on its centre, so that it may turn freely, it will move from one position to another, until it arranges itself with one pole to the north, the other to the south. This phenomenon is common to all parts of the world, and being so, it must be supposed to arise from some attractive influences existing between the earth and the magnet; we do not stop to determine the nature of that influence, but it is called terrestrial magnetism.

When the directive force of the magnet was first discovered, it was imagined that the poles pointed directly to the north and south poles of the earth, but this supposition is not strictly correct. Throughout Europe the north pole of the magnet deviates more or less, to the westward of the earth's north pole. This deviation is called the magnetic declination, or in other words, the deviation of the compass. There are, however, some places on the earth's surface where the magnet points directly north and south: and the line on which they are situated, encircling the earth, is called the line of no variation.

The line of no variation is supposed to commence at a point a little to the westward of Baffin's Bay. From this place it passes to the United States, crosses the Atlantic a little to the eastward of the windward West India isles, touches the north-eastern point of the continent of South America; and passes over the South Atlantic towards the south pole, but navigators have as yet been unable to trace it into this frigid clime. To the south of Van Dieman's land it appears again, crosses the Australian continent, and is found to pass into the Indian Archipelago, where it is

supposed to divide itself into two branches. One of these crosses the Indian Sea to Cape Comorin, traverses Hindostan and Persia to the western part of Siberia, and from thence to Lapland and over the North Sea. The other branch passes over China and Chinese Tartary to the Eastern division of Siberia, where it is lost in the eternal snows. It is probable that there is some middle line between these two, but at present we are ignorant of its position. Should this supposition be found correct, we shall have a line dividing the earth into two hemispheres, one upon which the magnet points directly north and south,—that is, on which the needle has no variation. But with even the present amount of knowledge, we may consider these two branches as forming a line of great breadth, and then we have the globe divided into two hemispheres. In that which comprehends Europe, Africa, and the western parts of Asia, and a greater portion of the Atlantic, the variation is westward. In the other, which includes nearly the whole of the American continent, the Pacific Ocean, and a portion of Eastern Asia, the variation is to the east.

The term geographical or true meridian is pretty well understood to mean the vertical plane which passes through the poles of the earth. By the magnetic meridian of any place, in contradistinction, we mean the vertical plane which passes through the direction of the horizontal needle at that place.

The value of a knowledge of the directive force of the magnetic needle has been appreciated from the earliest ages of the world. By its assistance the intrepid voyager for the

first time willingly lost sight of his native land, and guided his fragile bark over the bosom of the affrighted and angry waters. From that moment the ocean lost its power to terrify, and was in some degree brought under the power and controul of man. Nations have by its agency been united, civilization has extended, and the barrier between the union of man with man has been broken down.

The compass is a term describing a class of instruments, and not one in particular. It is a general name for all instruments which indicate the position of the magnetic meridian of a place, or the relation of any object to a magnetic meridian. It is constructed in various ways, according to the situation in which it is to be used, but in all the principle is the same. We may, however, divide the compass into two classes,—those which are intended to show the direction of the magnetic meridian, to which class belong the land compass, the mariner's compass, and the variation compass; and those which mark the angular distances of objects from this meridian, which are called azimuth compasses.

The compass of either class is nothing more than a magnetic needle, accurately suspended, with some arrangement by which its direction may always be determined. In order that accurate information may be obtained from it, but one thing is necessary,—to place it in a situation where it cannot be acted upon by any mass of metal. The proximity of iron used in the construction of vessels, is found to occasion, in some instances, a serious derangement in the direction of the needle.

CHANGE IN THE VARIATION.

The variation of the needle was not known for many years after the compass had come into use for the purposes of navigation; and it was not until the year 1622, that the variation was suspected of change. It was then discovered that in Europe it was moving from the east towards the west. In the year 1659, London was situated on the line of no variation, and from that time till within the last few years the needle has been gradually changing its direction, the north pole pointing more and more towards the west of the terrestrial north pole. In London its greatest deviation was 24° 30′ W. of the true meridian, which it attained in the year 1818. It is now on its return to the true meridian. From these remarks it must be evident that the line of no variation is constantly changing. In 1664, the line of no variation passed over Paris.

The cause of this remarkable phenomenon is still wrapt in mystery, though the recent researches in electricity seem to direct the attention to a still closer investigation of that agent.

But the magnetic needle is subject to a diurnal, as well as an annual change in its variation, which in some seasons of the year may amount to thirteen or fourteen minutes. This curious phenomenon was first described by Mr. Graham, who observed, that from about seven o'clock in the morning the north pole approached the west, and attained its maximum variation about two o'clock in the afternoon, after

which it returned, as he supposed, to its original position, there to remain until the following morning.

Considering the difficulty of accurately determining these small changes in the variation, it is not singular that the first observations should have been somewhat incorrect, as we now know them to have been; for careful examination has proved that, after the needle has attained its maximum variation about two o'clock in the afternoon, it gradually returns towards the east till the evening, and then has a second westerly direction, afterwards returning again so as to be nearly in the same position on the following morning. This daily variation is greater during the summer than the winter months, and greatest during June and August.

The cause of the diurnal change in the variation may, we think, be more easily determined than the annual. We may for instance fairly imagine the average direction of the needle to be the result of a cause influencing, in degree, the entire surface of the earth. But there are other causes in action which are of a more transient nature, irregular and fluctuating.

It is generally believed, though some who have had an opportunity of observing doubt the truth of the supposition, that the needle is affected by the Aurora Borealis, its deviation in some instances amounting to six or seven degrees. Volcanic eruptions also, as we know in the case of the eruptions of Hecla and Vesuvius, produce a considerable transient deviation. The electrical condition of the atmosphere, violent winds, the fall of snow, and other atmospheric changes, produce the same effect. These facts suggested to Mr. Bar-

low the propriety of neutralizing the constant cause, that which we call terrestrial magnetism; for it is evident, that, if we can place the magnet in such a position that it shall not feel the influence of the force which is constantly acting, then the action of the smaller forces which are variable, will be more apparent. Mr. Barlow effected this by arranging one or more magnets in such a position to the needle, on which the experiment was to be made, that the magnetic influence of the earth was destroyed. By this means he was able to magnify the daily variation almost without limit.

The variation compass, or the instrument used to exhibit the diurnal change in the variation, is not different in principle from others. It consists of a horizontal magnetic needle, which is of greater length than those used for other compasses; and as it is not required that it should move round the whole circumference of the box, it is enclosed in an oblong case, admitting a motion of about 20 or 25 degrees. A vernier scale and magnifier is generally attached to the instrument, which gives a facility of estimating the changes with greater precision.

DIP OF THE NEEDLE.

We have hitherto only spoken of the influence of terrestrial magnetism in the production of horizontal motions in the magnetic needle. Let us now suspend the needle in such a manner, that it may be free to move in a vertical plane. If a needle be delicately supported upon its centre

of gravity, the horizontal position of the magnet will be disturbed, and if the experiment be made in the northern hemisphere, the north pole will preponderate, or dip.

The dip of the needle, which was first observed by Norman, is not the same in all parts of the globe. The last observation on the dip in this country, was made at Woolwich, in November, 1830, by Capt. Sedgwick, who found it to be 69° 38′. As a general rule it may be stated that the dip diminishes as we approach the equator, and increases as we come near to the poles. Those points where the magnet is vertical, are called the magnetic poles; and the line which encircles the globe connecting the places where no dip is observed, has been called the magnetic equator. But it must be remembered, that the magnetic poles are not situated exactly at the poles of the earth's rotation, nor does the magnetic equator coincide with the earth's equator.

From the observations that have been made on the course of the magnetic equator in the Atlantic and Indian oceans, as well as that part of the Pacific which is nearest the South American continent, it appears to incline to the terrestrial equator, at an angle of about twelve degrees. But in the American continent, at a longitude of about 113° it joins the equator, and still further to the westward, at a longitude of 156° 13′, it is found at a considerable distance to the south of it. In the sea of China at 116° east longitude it is found north of the equator, and must therefore have crossed it, at some intermediate point. But at the eastern node, as we have already mentioned, it is on the south of the equator; and hence there must be some other place where it again

traverses the equator. There are then three points where the magnetic and terrestrial equators cross each other, and it is probable that there are four.

VARIATION OF INTENSITY.

Before we leave the subject of terrestrial magnetism, there is one other enquiry that demands our attention. The influence exerted by the earth upon magnetic bodies varies greatly in its intensity, in different places.

The method of measuring the intensity of terrestrial magnetism was first suggested by Mr. Graham, who proposed that it should be done by counting the number of vibrations made by a magnet when disturbed from its direction, till its return to equilibrium. The movements of the needle are governed by the laws which regulate the vibrations of the pendulum, and the intensity of the magnetic force is proportional to the square of the number of oscillations performed in any given time.

Humboldt and De Rossel were the first who made accurate experiments upon the magnetic intensity, and they have ascertained that the force of terrestrial magnetism is weakest at the equator, and increases towards the poles. It is a probable supposition that it will be found strongest at the magnetic poles, and weakest at the magnetic equator; but the principal object now is to determine the isodynamic lines, or, in other words, the lines on which the magnetic intensity is equal.

We might still further illustrate all these several effects of terrestrial magnetism by a simple hypothetical statement—a statement having no probable foundation in truth, though it was seriously proposed by a celebrated philosopher, to whom the science of magnetism is greatly indebted. Let us imagine the earth to contain a powerful magnet, lying in a position coinciding with the terrestrial magnetic axis; and let it be supposed that the magnet has a revolution round some point. This hypothesis, which Kepler ranks as one of the greatest of all scientific discoveries, is absurd enough in principle, but would produce all those effects upon the needle which we have just explained. But to make this hypothesis agree with facts, it must be assumed that the magnetic pole at the north pole of the earth, has properties similar to the south pole of a magnet; for as we have already seen, it is only poles of opposite names that attract each other. On account of this, some authors have seen fit to change the names of the magnetic poles, calling that which is directed to the north, the south pole. This change in nomenclature cannot fail to increase the ambiguity which the authors are anxious to avoid, and we think it desirable to continue the original terms. It is easy to perceive that the directive force of the magnet is readily accounted for by the hypothesis, and also its variation, and the annual change in the variation, which would result from a slow rotatory motion possessed by the terrestrial magnet. The dip is also explained by the same supposition, for it is evident that the nearer the needle be brought from the centre to the poles of the terrestrial magnet, the greater will be the deflection from the

horizontal plane, until at the poles it assumes a perpendicular position. This may be shown by passing a needle so suspended as to have a freedom of perpendicular motion, over the surface of a bar magnet. But although this supposition may tend to illustrate the general principles of terrestrial magnetism, it is not at all capable of explaining many other facts with which we are acquainted. The irregularity of the magnetic lines is altogether unaccounted for. There is also reason to believe that the northern and southern magnetic poles are not diametrically opposite to each other; and there are indications of two or more poles in each hemisphere having different degrees of intensity. It may in fact be considered as determined that there are two magnetic poles in the northern regions, one in Hudson's Bay, the other in Siberia; the former having much the greater intensity.

INFLUENCE ON SOFT IRON.

Hitherto we have only spoken of the influence of terrestrial magnetism upon the needle, and of one magnet upon another. It may here be asked, has the magnet no influence upon substances which do not possess the magnetic property? and to this question we must endeavour to reply.

If we take a piece of iron or steel, and bring it into contact with the pole of a magnet, it immediately becomes possessed of temporary magnetism, and during its connexion is itself a magnet. But as soon as the magnet is removed, all the acquired properties of the iron, or

steel, are lost, and it becomes incapable of producing any magnetic effect. The process by which it acquires these properties has been called induction. A few experiments will explain the fact, and illustrate the principle. If the north pole of a magnet be brought into contact with a small bar of iron, the iron becomes a magnet, and that end which is connected with the north end of the magnet is a south pole. But if the south pole of the magnet be presented, the end in contact will be a north pole. From which it is evident, that each pole of the magnet induces the opposite kind of polarity in that end of the iron which is least distant.

It has been discovered that the law governing this property of induction is constant, and that the induction is always inversely as the distance. This may be approximately shown by an experiment. Bring a piece of iron into the vicinity of a magnet, so disposing the distance that it may be capable of supporting a smaller piece of iron at the point farthest from the magnet. Now withdraw the magnet to a greater distance, and the iron will fall. But if we bring a smaller piece of iron to the end, it will be suspended; or if we bring a small piece of iron wire between the magnet and the iron, then its power will be apparently restored. By experiments varied in this manner, it may be shown that the induction is inversely as the distance.

A piece of iron, when thus temporarily magnetised by induction, will also have the power of attracting and repelling the poles of a magnet. Take a small needle suspended on a point, and present it to a piece of iron arranged as in the last

experiment, and it will be influenced according as the pole may be north or south.

A piece of iron, in a state of induced magnetism, has also the power of inducing magnetism in another piece of soft iron, and so on for a considerable series, and the last piece which receives the induced magnetism will be in every respect a perfect magnet.

An induced magnet has also the singular property of increasing the intensity of the magnet itself. Bring to one pole of a magnet a piece of iron to which has been attached a small scale. Ascertain the weight it will carry by adding weights to the scale. If a piece of iron be now brought near to the magnet, or in contact, and the experiment be repeated, the magnet will sustain a much greater weight.

From this general view of the principles of induction, we may discover the reason why a magnet attracts a piece of iron. It is not because it has any affinity for the iron, but because the iron becomes a temporary magnet, and the end connected with the magnet is in an opposite magnetic state to that pole of the magnet itself.

We have already described the action of magnets on each other as consisting chiefly in a repulsion between poles of the same name, and an attraction between poles of an opposite name. The action of one magnet on another is regu-

lated by a law first discovered by Mayer in 1760, and afterwards by Lambert: it is according to the inverse square of the distance. Coulomb, however, has deservedly the honour of proving the truth of this important principle by incontrovertible evidence.

Mr. Fox has recently made some experiments, which tend to prove, that the reciprocal force of two magnets at small distances, is as the direct inverse ratio of the distance, not as the inverse ratio of the square of the distance. Mr. Fox states that when the two magnets he employed were separated about two thousandth of an inch from each other, their force was equal to only one half of that when in contact. When the distance was one thousandth of an inch, the force was only one quarter; when five hundredth of an inch, only one eighth; and so on, in the direct inverse ratio of the distance until they were one-eighth of an inch, or more asunder; after which the attractive power seemed to approximate to the inverse ratio of the square of the distance.

Dr. Ritchie objects[1] to Mr. Fox's conclusion that the mutual attraction of two magnets is inversely as the distance, and supports the accuracy of the law, always before adopted by philosophers, of the inverse *square* of the distance. The Doctor admits the accuracy of the experiments, but denies the conclusion. His first objection is founded on the fact, that the position of the magnetic pole depends on the form and length of the magnet. In proof of this statement he adduces Biot's experiment, in which a steel wire, twenty-

[1] Phil. Mag. 3d Series, vol. viii. p. 55.

four inches long, properly magnetized, was shown to have its pole an inch and a half from the extremity, the distance from the extremity, however, decreasing with the length of the magnet.

Dr. Ritchie further objects that Mr. Fox's experiments confirm and are a beautiful illustration of the law of inverse squares, investigated by Coulomb; for, he says, if the distances between the poles of two magnets in three different positions be, as 2, 3, and 4, then "the attractive forces will be inversely as 2^2, 3^2, 4^2, that is $\frac{1}{4}$, $\frac{1}{9}$, $\frac{1}{16}$; but $\frac{1}{9}$ is nearly the half of one-fourth, and $\frac{1}{16}$ nearly the half of $\frac{1}{9}$, as Mr. Fox found by actual experiment."

To the last-mentioned objection Mr. Fox very properly replies; "I cannot admit the justness of Dr Ritchie's conclusions, unless it can be shown that the results of my experiments are conformable to the law of the inverse squares, of the distances throughout the whole series of nine or ten removals of the magnet, calculating from any assumed points whatever in them.[1]"

The results obtained by Mr. Fox are, however, we cannot doubt, only true in reference to magnetic attractive forces at very small distances. The fact was observed by Mr. Snow Harris in the year 1827. Speaking of a table containing the results of some experiments on this subject, he says, "It may be perceived that the corresponding forces at near approximations do not materially vary from a simple ratio of the distance. The deviation from the law of the inverse

[1] Phil. Mag. vol. viii. p. 108.

square of the distance observed, in all the near approximations of the magnets, may happen either in consequence of the distant polarities having passed a certain limit, or otherwise, from the inductive action not going on with the same freedom, at some point approaching saturation [1]."

FORMATION OF MAGNETS.

Magnets have another effect upon ferruginous substances besides that already mentioned; the production of permanent magnetism in hard steel. In this instance, as well as that in which temporary magnetism is imparted, the power is gained by induction. That we may present a tolerably accurate view of the science now under consideration, it is necessary that an explanation should be given of some methods by which artificial permanent magnets may be formed.

Magnets may be formed by percussion. Thus for example, if a poker be held in a vertical position, and be struck three or four times with a heavy blow, it will become magnetic. To obtain good permanent magnets, steel bars should be used, as the permanency depends upon the hardness of the iron. The rectangular prism is found by experience to be the best shape for the bars that are to be rendered magnetic. Now, supposing we had no artificial magnets, we might obtain them by taking bars of iron, and hammer-

[1] Trans. of Royal Society of Edinb. vol. ii. p. 312.

ing them while in a vertical position. The lower end would acquire a northern polarity, the upper a southern, and this is the result of the inductive influence of terrestrial magnetism. If the iron bar be hammered upon a mass of the same metal, both being placed in a vertical position, the magnetism of the bar will be increased, for both will be rendered magnetic, and the induced magnetism of one will increase the power of the other.

Small magnets may be formed by simple juxta-position. To develope magnetic properties in this way it is not sufficient that one end of the steel bar be in contact with the magnet, for then one end will be more strongly magnetised than the other. The bar must be placed between the opposite poles of two magnets, having nearly the same power, and it is found that the magnetism thus induced is more than twice as great as that produced by a single magnet.

But the greatest magnetic power is gained by bringing every part of the bar under the influence of the magnetising pole. This process is called magnetising by the touch, and it will be necessary to speak of some of the most important methods, which have been proposed.

The first method employed, was that called the single touch. The operator, in this experiment, places upon a table the bar to be magnetised, and taking a magnet, draws one pole in a vertical position over the surface of the bar; after this has been done, the process is repeated, and continually, till the effect has been obtained. Considerable care is required in this operation, or the bar will acquire more than two poles.

Dr. Knight improved upon the method of magnetising by the single touch. He used the opposite poles of two magnets, applying poles of different names to the opposite halves of the bar. Take two magnets, and, joining them by their opposite poles, place them on the bar, in such a position that their point of junction may be on its centre. By drawing them in opposite directions, each pole will receive the magnetism it is to permanently possess. This method was found to answer exceeding well with small bars, but was not equally effective in magnetising long ones.

Duhamel invented another process by which bars of any length may be rendered magnetic. He took two bars of hard steel, and, placing them parallel to each other, united them by bars of soft iron. The opposite poles of two bundles of magnets were then placed together on one side of the parallelogram, and slowly separated. The process being repeated on each bar, and on each side of the bar, a strong permanent magnetism may be obtained. Epinus improved upon this process by using magnetic steel bars as the cross pieces. Several other methods have been employed, most of which have advantages under particular circumstances.

We have here spoken of the production of permanent magnetism in ferruginous bodies, but the property is only permanent in degree, for there are many causes which tend to disturb and even to destroy it. The magnetism is then said to be dissipated. If for instance we keep a magnet in any other position than that which it would assume from the uncontrolled action of terrestrial magnetism, its power is weakened, and will at last be entirely destroyed. If two

magnets be kept with their similar poles united, the power of the magnet is dissipated, and the weaker will sometimes have its poles reversed. Heat also will destroy the magnetic power, and a concussion or violent rubbing will produce the same effect.

Magnets may, on the other hand, be strengthened by an attention to the converse of these statements. The best provision for the security of magnets is the application of an armature, that is to say, their poles should be united by a small piece of soft iron. When it is required to unite two or three magnets so that they may act as a single magnet, they are bound together by a piece of soft iron, which considerably increases their magnetic power.

The influence of magnetism upon the going of clocks and timepieces, has been studied by many ingenious persons. In the year 1798, Mr. S. Varley published an interesting paper on the subject[1]. This gentleman represents himself as having studied for many years the theory of clock and watch making, and as having been engaged for some time in an extensive manufactory of watches. From his own statement it is evident that some persons, previous to the publication of his paper, were of opinion that the balance wheels of watches might possess the magnetic property, but that it was sufficiently powerful to alter the rate of going in a watch placed in different positions, no one had imagined. Mr. Varley's attention was called to the subject from the circumstance of his having in his own possession a watch of

[1] Tilloch's Philosoph. Mag. vol. i. p. 16.

excellent workmanship, but exceedingly irregular in its action. When the pendulum spring was removed, and the balance placed on the poising tool, it was soon found that magnetism was the deranging cause. So strong was the magnetism of the balance, that when its plane was in an horizontal position the polarity overcame the friction upon the pivot, and it constantly ranged itself with its poles towards the poles of the earth.

To determine the amount of influence possessed by magnetism the balance was replaced, and the watch put in a horizontal position, with the north pole of the balance towards the terrestrial pole of the same name :—in this situation the watch gained five minutes thirty-five seconds in twenty-four hours. When the north pole of the balance was towards the south pole of the earth, the watch lost six minutes forty-eight seconds in the same period. After discovering these results, a gold balance was substituted, and the error in the rate of going was entirely corrected. Mr. Varley made experiments upon many other steel balances, but was unable to find one without magnetic polarity.

Since the publication of Mr. Varley's paper much attention has been paid to the influence of magnetism on the rates of chronometers. To correct any source of erro to which the instruments may be exposed is so important, that all persons who are engaged in philosophical pursuits have watched this investigation with peculiar interest. We cannot, however, in this place, do more than direct the reader to the papers which have appeared in the Philosophical Journals [1].

[1] See Mr. Fisher's paper in Philosophical Transactions for 1820 and

PRODUCTION OF MAGNETIC CURRENTS BY ROTATION.

In the year 1824, M. Arago discovered that if a plate of copper, or other metal, be placed under a magnet, it will sensibly affect the extent of its oscillations, and bring the needle to rest in a shorter time than would otherwise have been required. This observation led him to the examination of the phenomena, and ultimately to the discovery of a most interesting class of effects. In December of the same year, Mr. Barlow, assisted by Mr. James Marsh, commenced a similar investigation. "Mr. Barlow having requested me," says the latter gentleman, "to ascertain, by means of one of the turning lathes in the Royal Arsenal, whether by giving to an iron body a rapid rotation, any change could be distinguished in its magnetic state during the motion, or after it had subsided, I did, accordingly, about the beginning of December, 1824, attach a small howitzer shell to a lathe, admitting of a rapid motion, and having placed a small compass very near to it, I perceived at once, that the needle was considerably deflected, but it returned to its original direction as soon as the motion ceased."

Similar experiments were afterwards made by Mr. Barlow; but, finding himself embarrassed with the iron-work of the lathes and other machines, he constructed an instrument "by means of which he succeeded in deducing the laws which

Mr. Harvey's remarks in Edinburgh Philosophical Journal, vol. x. p. 1. See also Mr. Barlow's papers on the Local attraction of vessels, Edinburgh Philosophical Journal, vol. ii. p. 65.

regulate and determine the direction of the needle in all cases and in all situations." It was not till April, 1825, that Mr. Barlow was made acquainted with M. Arago's experiments. "The account he had of M. Arago's experiment," says Mr. Marsh, "was that, by placing a copper-plate on a vertical spindle, the plate being horizontal, and then placing just above it a light compass needle, but independent, of course, of the plate; on causing the spindle and plate to revolve, the needle was considerably deflected, and more and more as the velocity was increased; so that, when the plate was put into rapid rotation, the needle also began, after a few vibrations, to revolve, and at length with considerable velocity."

This account is interesting, as showing the manner in which two philosophers, at a distance from each other, may be led by a similar course of thought and experiment to the discovery of the same principles. We shall not, however, refer more at large to the observations of Arago and Barlow, but direct the attention of the reader to an instrument invented and manufactured by Mr. E. M. Clarke, of Lowther Arcade, for the exhibition of the facts they discovered.

Fig. 54, represents an instrument by which either a vertical or horizontal motion may be obtained, and it may, therefore, be made serviceable for many experiments beside that we are about to describe. From the end of the horizontal arm is suspended by a string a bar magnet. Beneath the magnet there is a circular disc of copper, which is made to revolve from its connection by a band with the horizontal wheel. A plate of glass is fixed between the magnet and the copper disc, so as to prevent the action of currents of air. As soon as the disc begins to rotate, vibrations will be observed in the magnet, and after a short time, both will rotate in the same direction.

Fig. 54.

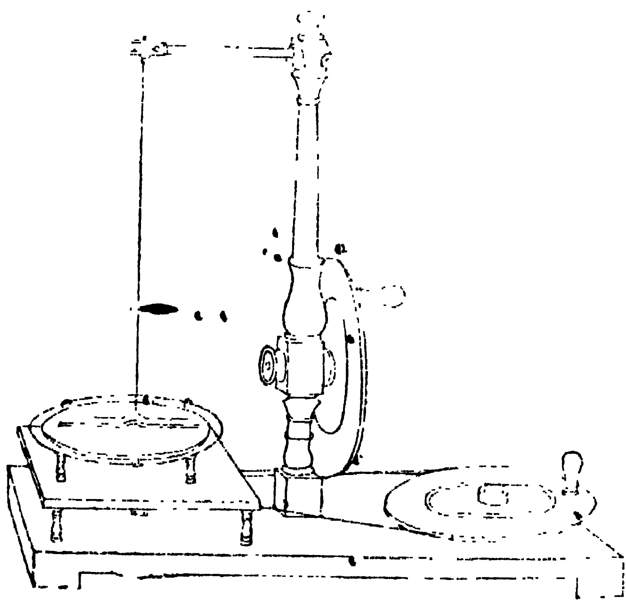
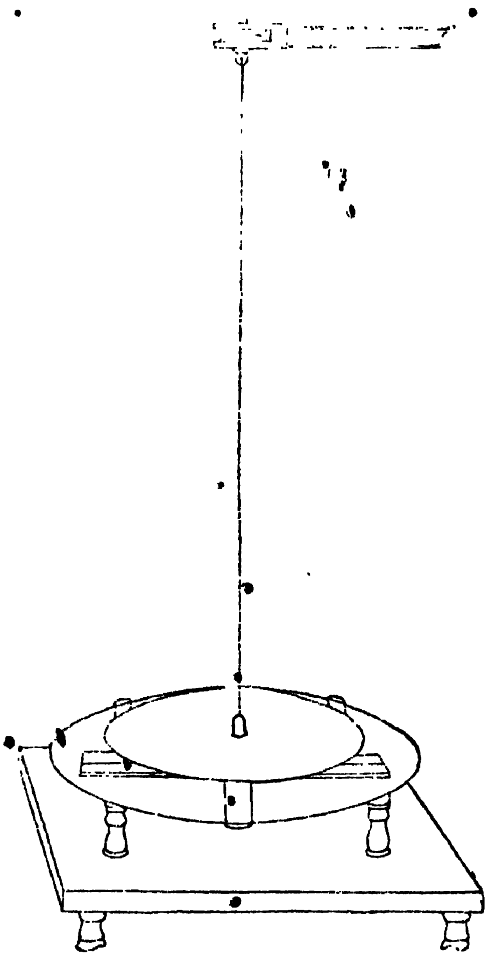


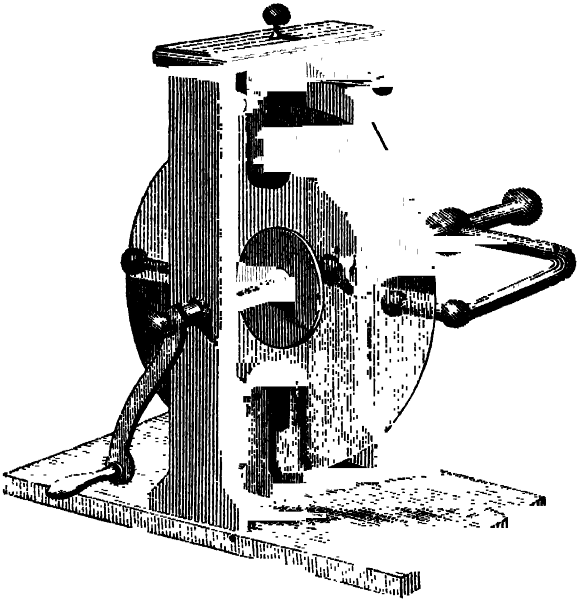
Fig. 55, exhibits the reverse experiment—the rotation of the magnet producing that of the disc. From both the experiments it will be evident, that, by rotation, a temporary

Fig. 55.



magnetic state may be induced in metals supposed to be destitute of the property.

This condensed explanation of the science of magnetism will put the reader in possession of some important facts, relating to the influence of magnets on each other, and of terrestrial magnetism on them. The relative influence of magnetism and electricity we cannot describe until we have taught the latter science, and our now very limited space will prevent us from attempting even a brief account of the extensive science of Electro-Magnetism.



ELECTRICAL MACHINE.

CHAPTER VII.

ELECTRICITY.

The word Electricity had a few years since a very confined application to the phenomena presented during the development of certain forces by friction. The experiments of modern philosophers have proved that the same agent is deve-

loped by chemical action, heat under certain circumstances, magnets, and the muscular action of a few fishes. The discovery at different times of these several means of obtaining electricity has caused the formation of distinct sciences, which are distinguished from each other, by the cause from which the electricity is obtained. Although we feel the importance of avoiding a too hasty generalization, yet in a certain stage of the progressive development of the relations of scientific truths, it is necessary that there should be some persons who, careless of the doubts of others, are willing to break the trammels of custom, and exhibit those more perfect views of natural phenomena which successive discoveries have revealed. We believe that the electrical sciences present such an opportunity at the present time, and the attempt would have been made in this work, if it had not been intended for the use of those who are commencing the study of experimental philosophy.

From these remarks, the reader will perceive we are of opinion that the phenomena of common or ordinary, voltaic, magnetic, thermal, and animal electricity, arise from the same agency, acting under different circumstances. The only means of proving an identity of cause is by ascertaining an identity of effect; nor is it necessary for this purpose, that there should be the same amount of effect, for we are well assured that in nature there is a constant variation in this particular, arising from modifying causes when the same agent is active. In the following pages it will clearly appear, that the effects produced by what are called the several kinds of electricity, are only different

in degree, and hence we conclude that the same agent is acting in each.

Before we commence the investigation of the several branches of the science of electricity, it may be convenient to the student, that we should take a general view of the various means by which it may be developed. Whenever friction is produced, whenever voltaic combinations are formed, from every magnet, and every unequal change in the temperature of metallic substances, electricity is developed. How wide then is the influence of that agent, and reasoning from its universal distribution, how important it must be to the good order and harmony of material existence. Both animate and inanimate substances are in some degree under its controul. As the principle of life has an intimate, though mysterious connexion with matter, and is invigorated or depressed, by the condition of its material habitation, and surrounding existence, it cannot be free from the same influence. It is, however, more than probable that it is not only necessary for the continuance of the present condition of bodies, but that its presence governs all chemical changes, and watches over, if it does not sustain, the order of all material existence. The disturbing forces on the surface of the Earth, are constantly in action; and by each the electric equilibrium is affected. Nor is the condition of the interior of the globe less liable to change. A metal cannot have an alteration of temperature, without putting in motion electric currents, and what is observed in the instance of a small metallic body on our laboratory table, is present in the great reservoirs of metallic ore in the interior of the Earth.

The unequal transmission of heat, from the surface of the Earth, gives a varying temperature to these immense accumulations of metallic substances. This is sufficient to put in motion thermal electric currents, which are, in all probability, in many instances aided by the presence of ternary arrangements developing voltaic electricity.

These currents must find a passage to the surface of the Earth, and every tree and vegetable blade becomes a medium of dissipation. There are, therefore, causes both on the surface and in the interior of our world, which tend to disturb the electric equilibrium. In the atmosphere it is collected in clouds, from which it descends to the Earth; nor need it be a matter of surprise, when we consider how vast an accumulation of electric fluid is sometimes present in the clouds, that there should be some countries where the roll of the thunder, and the flash of the lightning scarcely cease. But at the same time we must admire the beauty of those arrangements by which the disturbances of the electric equilibrium are corrected, and the fair forms of nature preserved from the devastating and consuming influence of an inordinate accumulation.

COMMON OR ORDINARY ELECTRICITY.

The effects produced by electricity generally, are similar to those which would be obtained from the action of a subtle fluid, and hence it is, we speak of the electric fluid. In that state to which we are now about to allude its effects are such

as would result from great condensation, shown by its sudden and violent action when accumulated in a Leyden jar. As water, when pent up by some powerful resistance, sweeps away all lesser obstacles when the greater is removed, and forming for itself a channel, flows on till it attains a uniformity of surface, so the accumulated and the confined electric fluid, when once it has a means of escape rushes from its place of rest, and instantly restores equilibrium.

The most common method of developing the ordinary electricity is by friction. All bodies are capable of excitement under restrictions to be hereafter mentioned. When two bodies are rubbed together, their electrical conditions are disturbed, one being charged with more, and the other with less than its natural quantity. And this effect will be obtained, even though the bodies are to all appearance exactly alike, for Epinus says, that when he rubbed two equal pieces of glass together, they were oppositely electrified.

Either plus or minus electricity may be obtained from any substance by changing the rubber. Thus a piece of glass excited by a silk handkerchief, will be positively electrified, with the back of a living cat negatively. The character of the electricity will also depend on the degree of smoothness. Colour also has an influence, for if black and white silk are rubbed together, the former will be negatively, the latter positively electrified.

Electricity may also be developed by the friction produced in the act of sifting. This may be proved by sifting some fine zinc filings through a silver sieve, or silver filings through a zinc sieve, on the top of a gold leaf electrometer. When sub-

stances are rubbed together, as in the act of trituration or pounding, the electrical states of those substances are changed. Take a smooth plate of glass, and trace any letter upon it with the knob of a jar charged positively, and the same or any other letter with the knob of a jar charged negatively. Then rub togther some red lead and sulphur in a mortar, and dust the plate with the mixture, or filling the mouth of a pair of bellows, blow it on the plate. The sulphur will attach itself to the letter made with the negative jar, and the red lead to that made with the positive. Only one reason can be given for this appearance; the sulphur is positively, and the red lead negatively electrified by rubbing.

Electricity is also often developed when a substance is torn asunder by mechanical force. When a piece of dry wood is split, one piece will be in a positive, the other in a negative state.

Electric phenomena are also developed when a substance changes its state, from a solid to a liquid, or from a liquid to a vapour. If a hot plate be placed on the cap of a gold-leaf electrometer, and a little distilled water be dropped on it, the water will instantly be vaporised, and the leaves will diverge, giving evidence of the liberation of the electricity.

The action of heat on crystallized bodies also disturbs their electric states. Tourmaline is a substance peculiarly adapted to prove the fact. This curious mineral, called by the ancients, Lyncurium, and by Linnæus, the Lapis Electricus, or Electric Stone, was first examined by Epinus in 1756. His experiments were published in the Memoirs of the Berlin Academy. When the temperature of a crystal was raised from 100° to 212° Fahrenheit, one end was charged with

positive, the other with negative electricity. Boracite, Topaz, Axinite, and other minerals, are also capable of excitement in the same manner. M. Haüy is of opinion, from the result of his researches, that the process of crystallization is dependent on electricity.

Volta was the first who ascertained that the electric condition of bodies is disturbed by contact. This was proved by taking two discs, one of copper, the other of zinc, or still better silver, about two inches in diameter. To these were attached glass handles. The plain and smooth surfaces of the discs were then made to touch, and when separated, their electric conditions were examined: the copper was uniformly in a negative, and the silver in a positive state.

Hence then, it will appear, that the mere contact of two insulated dissimilar metals, without friction, is sufficient to disturb their electric condition; but no theory has been yet proposed, by which this extraordinary fact can be accounted for. The silent transmission of electricity, during a momentary contact, must be produced by some force, which we are at present altogether unable to trace.

Electricity is also very commonly developed by substances, when acting chemically on each other. Becquerel has proved, that an acid, when it has a chemical action on a metal, becomes positive, and the metal is in a negative state: —this is the case when diluted sulphuric acid attacks iron filings. From Dr. Wollaston's experiments on the electrical machine, we may learn that electricity is set free by the oxidation of metals, and that the electricity of the machine is partly derived from this source.

VOLTAIC ELECTRICITY.

When any three elements, two of which exhibit chemical action, are in contact, electricity is given out; but the fluid is in a different state from that obtained by friction. The voltaic battery gives a continuous stream or current of electricity, but it has little or no intensity. The common electricity has so much energy when in motion, that it is able to overcome the resistance of a bad conductor; the voltaic electricity has not this power. If a ball, for example, be brought within an inch or two of the conductor of a machine, the electricity will pass from one to the other, although dry air, which is a bad conductor, should intervene between them. But let the two ends of the conducting wires be brought to the same distance from each other, and no effects will be observed; they must in fact, be almost in contact before there can be any transmission of the electricity. On the other hand, the quantity of electricity is much greater from the voltaic battery than from the common machine, for in the former there is a constant current, and in the latter the fluid is incessantly interrupted.

MAGNETIC ELECTRICITY.

Electricity may also be obtained by the action of the magnet, which is, we think, its most important source. The magnet was known ages before the existence of electricity

was suspected, and yet, when its principles had been ascertained, and all other known means of setting it free had been discovered, the magnet was found capable of exciting the same agent. There are many reasons why the magnet should be preferred as the best means of showing electric phenomena. It is in the first place able to exhibit the intensity effects of the common, and the quantity effects of the voltaic battery with equal facility. It is at the same time less affected by external causes than either. The machine will only act in a particular condition of the atmosphere,—the presence of moisture effectually prevents any results. The voltaic battery, on the other hand, in its common form, soon loses its active energy, and decreases in power in proportion to the time it is used. Both are attended with much trouble in the preparation, but the magnetic machine, on the other hand, is always ready for use, and will exhibit more effect than either separately. It cannot then be disputed that we should act wisely in placing the magnet first among the various sources of electric excitement.

THERMAL ELECTRICITY.

The electrical condition of metal is disturbed by an unequal temperature. If a bar of antimony, bismuth, or other metallic substance be heated at one place, and cooled at another, a current of electricity is instantly put in motion. In this case, however, the intensity is so small that little or no effect can be obtained; but when many plates are connected together, the results are very striking.

ANIMAL ELECTRICITY.

The term animal electricity has been applied to many distinct classes of phenomena. The free electricity of the human body has been sometimes so called, and at one period the voltaic electricity had the same name: we must, however, confine the use of the expression to that agent developed by a few fishes, called by way of distinction the electrical fishes.

There are then five sources of electricity; not five distinct kinds of electricity as some suppose, but the same agent in different states. These we shall examine separately, but the reader, by bearing in mind the unity of the agent, will be greatly assisted in his attempt to acquire a knowledge of the science.

PRODUCTION OF ORDINARY ELECTRICITY.

There are few scientific subjects which have been so generally studied, as the science of Electricity. This will appear at first the more singular, when we consider that it is the branch of physical knowledge of the most modern growth. It has, however, been the most prolific, and has thrown off many subsidiary shoots which have yielded much fruit to the cultivator. The Science of Astronomy first engaged, without doubt, the attention of men, and when in maturity, Electricity, as a principle, much more as a science, was unknown. The study of the heavenly bodies was the most

obvious pursuit of the early inhabitants of the Earth, for it is a science of observation. On the same account it is still a popular amusement, though by no means a common study, —there are few who are not acquainted with the wonders it reveals, there are fewer still who understand the causes which produce them. Electricity is an experimental science, and consequently was, in some degree, dependent on the progress of the Arts.

The facilities which have of late been offered for the construction of instruments, and of apparatus generally, could not fail to attract attention, and the ease with which they can be obtained has enlisted many in the study of Electricity. There is so much to please the eye, and to excite surprise in the common experiments, that the elementary facts of electricity are, perhaps, more generally known than any other branch of physics. It is also a subject peculiarly adapted to please, and to excite the curiosity of young persons, and is therefore often introduced to their attention by those parents and teachers, who feel the value of creating or encouraging habits of observation.

The ancients appear to have been aware that amber, when rubbed, becomes possessed of the property of attracting light bodies. Theophrastus says, that the lyncurium stone which is supposed to be the tourmalin of modern mineralogists has when rubbed, an attractive power, and draws to itself, not only straws, and light pieces of stick, but thin pieces of copper and iron. These phenomena engaged the attention of the Greek philosophers, as among the occult wonders of the physical system. They had no idea of the principle which

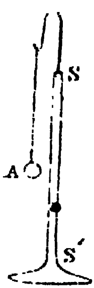
gave them birth, and do not seem to have made any experiments calculated to acquaint them with the cause of the appearance that excited their wonder.

In the beginning of the eighteenth century, when the attention of intelligent and observing men was so singularly and powerfully impressed with the necessity of an experimental investigation of physical agents, many attempts were made to discover the nature of that principle, developed by friction on the surface of amber. Dr. Gilbert, a physician of eminence, ascertained that many other substances acquire the attractive power by friction. Between the years 1720 and 1736, Mr. Gray published some papers on electricity, in the Philosophical Transactions. This philosopher discovered that some bodies had the power of conducting electricity, and that others had not. He also made some experiments which induced him to believe that certain bodies could be excited by friction, while others could under no circumstances be made to possess the attractive power: and consequently, he divided all substances into electrics, and non-electrics. This arrangement has been adopted, even by many modern philosophers, yet there can be no doubt that all substances are capable of excitement by friction, though not in an equal degree. If we rub a rod of glass with a piece of silk, taking care that both be perfectly dry, we shall find that the glass will be electrified, or in other words that it will acquire the property of attracting light substances. The same effect will be produced if we rub a stick of sealing wax with flannel, or a woollen cloth. Let us, then take a rod of metal, brass for instance, and rub it with a black cat's skin, we shall

be quite unable to produce the attractive power. It might consequently be supposed that the brass was a non-electric, a substance incapable of excitation. Let us not, however, judge hastily; there may be some cause altogether independent of the excitation of the substance that prevents the production of the effect observed in the former instances.

Before we explain this more particularly, it may be well to turn to another course of experiments, which will considerably assist us in our inquiries. The electricity which is excited upon the surface of glass or sealing wax, may be conveyed to some independent body, which will become electric without friction.

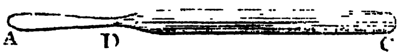
Fig. 56.



Let A fig. 56, be a pith ball suspended to a hook fastened to a glass stand S S'. Take a piece of sealing wax and rub it briskly with a flannel so that it may be excited. Then bring it into contact with the ball A. As soon as the two bodies are brought together, the ball A receives a certain amount of electricity from the excited sealing wax, and the proof of this is the existence of a repellant force, which is almost immediately called into action. We may therefore suppose the pith ball A to be charged with electricity, or in other words excited by contact, with the electrified wax. We will now touch it with a glass rod, but none of its electricity is carried away, for it will still be repelled by an excited stick of sealing wax. If it be touched with resin, the same result will be observed: but if we bring a piece of iron wire or any other metal near it, all the electricity will be instantly lost.

From these experiments it will evidently appear that glass and resin are non-conductors of electricity, and that the metals are conductors. Now apply this fact to the experiments first made. We may hold sealing wax in the hand and excite it with flannel, or glass with silk; but if we take a metal it will be impossible to have any proof of excitation, for as quickly as the electricity is produced, it is carried away by the human body, which is a conducting substance. If we would determine the question, are the metals electrics, we must attach them to bodies which are not conductors.

Fig. 57.



Take a cylinder of brass C D, fig. 57, and fix it into a glass handle A D. Rub it with a black cat's skin, and it will be soon electrified, and acquire the property of attracting light substances.

From the experiments which have been made, there can be no doubt that all substances may be electrified by friction The flannel with which sealing wax is rubbed, is excited as well as the wax; two pieces of silk cannot be drawn together through the fingers, without being electrified. How vast then must be the influence of this agent in nature. If no two substances can be rubbed together without a disengagement of electricity, there must be a constant disturbance and re-establishment of electric equilibrium, which may even in the present stage of our investigations be supposed to produce many important natural phenomena.

This immediately leads us to inquire if the electricity of substances is the same in all instances. Are there, it may be

asked, any points of difference between the electricity of one substance and another? is there, for instance, any difference between the electricity produced by the friction of sealing wax, and that developed on the surface of glass. To determine this question, we will take two pith balls, and suspending each by a silk thread, which is a non-conducting substance, charge one with the electricity of wax, and the other with the electricity of glass. Then bring the two balls near to each other, and it will be observed that an attraction exists between them, from which it may be supposed that an electrified body has an influence upon an excited substance, as well as upon one that is non-electrified. Let us now take the two balls and excite both with the same electricity, whether it be that from glass or wax, and bring them near to each other: it will be observed that they repel each other. If these experiments be continued by observations upon the influence of other excited bodies, it will be discovered that there is always a repulsion between two bodies charged with the same electricity, and an attraction between those which are excited with the electricity of some different bodies. We do not mean to say that if we take promiscuously any two substances, and excite them, there must necessarily be an attractive power between their electricities. There are two classes of bodies, if we may be allowed the expression, in relation to electricity, and any two excited substances of either class would repel each other, and an excited substance of one class will attract one of the other class. At the head of one series we have the resins, at the head of the other vitreous bodies, and hence we call one kind of electricity re-

sinous and the other vitreous, or according to the nomenclature of other authors, negative and positive.

There are many interesting experiments which may be made with exceedingly simple apparatus to show the presence of electricity, developed by friction, and the influence which it has upon itself.

Suspend a feather to an insulated stand, fig 56, that is a stand made entirely, or in part of a non-conductor, so that the electricity communicated to any substance shall not be carried away to the Earth. Then take a piece of sealing wax, and after rubbing it briskly with flannel bring it near to the feather, which will be attracted by it, and so strongly that it may be easily carried over the stand.

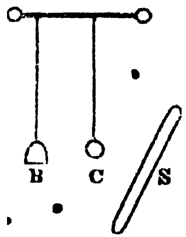
The presence of electricity may be always determined by the attraction of light bodies, or by the repulsion which is produced, when these bodies become charged with the same electricity as the excited substance. The instruments used for this purpose, are called electroscopes or electrometers. One invented by Mr. Bennett, and called the gold leaf electrometer, is shewn in fig. 58. It is a glass vessel with a brass disk, to which is attached a flattened wire with pieces of gold leaf or pith balls. If any excited body be brought into contact with the brass cap, the gold leaves or pith balls being similarly electrified will repel each other, and thus give evidence of the presence of electricity.

Fig. 58.

A more detailed description of this important instrument will be given in another part of this chapter.

The principle of attraction, or repulsion, as resulting from electricity of the same, or of opposite names, may be illustrated by the following experiment, which is a modification of one commonly known as the electrical bells.

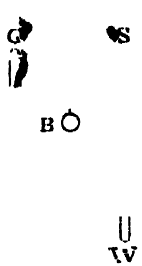
Fig. 59.



Let B, fig. 59, be a hemisphere of metal, representing a bell without its clapper, and let C be a small metallic ball, and each of them be suspended to a rod by silk threads, or some other non-conducting substance. Bring an excited roll of sealing wax, S, near to the clapper C; and it will be attracted to it, for it is a light unelectrified body. It will then be charged with electricity of the same kind as the wax, and will consequently be repelled. Being an excited body it will approach the unelectrified body B, and communicating its electricity will be repelled and remain suspended between the two electrified substances.

Take an excited glass rod G R, fig. 60, and sealing wax S W, and place them in such situations that they may act

Fig. 60.



upon the suspended ball B. Let us suppose it to be first attracted by the glass:—after it has acquired a portion of its electricity, it will be repelled, and as electricities of different kinds or names attract each other, it will then be drawn to the sealing wax, where it parts with the electricity first acquired and receives that of the other kind, which causes an attraction towards the

excited glass. Thus a constant oscillatory motion is produced until the electricity of both substances is entirely carried away, and the ball being no longer acted upon comes to rest.

THE ELECTRICAL MACHINE.

The Electrical Machine is an instrument employed for the development of electricity, for the purpose of accumulation. The celebrated Otto Guericke, burgomaster of Magdeburg, invented the Electrical Machine, as well as the air-pump. Having cast a globe of sulphur in a glass sphere; he broke the glass, which was not then known to be an electric, and mounted the sulphur on an axis. Sir Isaac Newton discovered the fact that glass is capable of excitement by friction, and Mr. Hawksbee used a glass globe in the construction of an electrical machine.

Professor Winkler of Leipzic, applied the cushion to excite the glass instead of the hand. Gordon, a Scotch Benedictine monk, used a glass cylinder in place of a globe. Even at this time the mechanical contrivances by which the electrical machine was made to revolve, and the conductor was attached to it, were exceedingly rude. Almost every person who had occasion to use the instrument, added some improvement, suggested by the inconvenience he felt. We are indebted to Dr. Ingenhouz for the plate machine, but since its introduction it has been greatly improved by Cuthbertson, Woodward, and others. This machine is now

very commonly used by electricians, and is generally preferred, because a larger surface is subject to the action of the rubbers in a given space of time, than in the cylindrical machines.

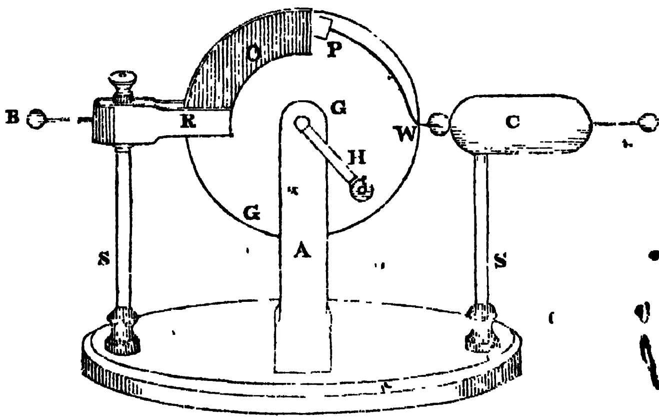
The Plate Electrical Machine represented at the commencement of this chapter, consists of a glass disc, which is made of greater or less diameter, according to the purpose for which the machine is required. The plate is so fixed in a wooden frame, as to revolve on its axis by turning a handle from which the motion is communicated. To the top and bottom of the frame a pair of rubbers is attached, and the plate must consequently suffer friction, as it has to revolve between them. To each rubber a piece of oiled silk is attached, so that when the electricity is excited upon the surface of the glass, it may not be conducted away by the air which impinges on the plate, but be carried to the conductors, which are furnished with points, for a reason we shall presently have occasion to explain. The conductors are made of metal, generally of brass, and from them the electricity may be conveyed at pleasure, either to be accumulated in a Leyden jar, or to act immediately on any substance.

An electrical machine then is nothing more than an instrument, so formed, that a large surface of an electric may be exposed to friction, and the electricity, thus developed be readily conveyed away. The plate machine is allowed to be the best, as it is convenient of carriage, even when of a large size, and presents a considerable surface. This instrument, however, is constructed in various ways, according to the

fancy of the instrument maker, or the purchaser; of these we shall only mention one, proposed by Mr. Clarke, which seems to be a good arrangement for small instruments.

G G, fig. 61, is a glass plate fixed between two uprights, (one of which, A, is shown in the diagram,) and made to revolve by the handle H. R is the rubber enclosing a certain portion of the plate, and B is a brass ball by which the rubber is connected with the Earth. P are the points collecting the electricity excited by the rubber, and brought over one-fourth of the plate by the oiled silk O. W is a wire connecting the points with the conductor C. S S are glass rods supporting and insulating the conductor and rubber. The whole arrangement is supported on a wooden stand.

Fig. 61.



It has been found by experiment that the machine has much greater energy when the rubbers are covered with an amalgam. The amalgam commonly used, is formed of equal

weights of tin and zinc, which when mixed by melting, are shaken in a wooden box, with twice their weight of mercury, till the compound is cold. When cold the amalgam is reduced to powder in a mortar, and mixed with lard, so as to form a paste.

Dr. Thomson recommends the following proportions—

Zinc	. . .	8·5 parts
Tin	. . .	7·25
Mercury	. .	37·5

Such an amalgam, he says, is apt to crystallize, but is easily made fit for use by pounding in a mortar. The facts stated in the previous remarks may be reduced to the following propositions.

1. Every substance suffers electric excitement by friction, but the worst conductors are the best electrics. Thus glass and the resins, which scarcely conduct at all, are the most susceptible of excitement, and the metals which are the best conductors are the worst electrics.

2. The electricity of bodies so differs in character, that many persons have believed in the existence of two electricities; one of which they call resinous, the other vitreous; while others have considered substances to give off a positive, or a negative electricity, according to circumstances; a supposition supported by many curious experiments, and especially by the fact, that the kind of electricity obtained from any substance will be regulated by the character of the body, by which it is rubbed. It matters but little in the present stage of our investigations what theory we may adopt, nor indeed is it our intention to enter into the curious inquiries by which

theorists have endeavoured to support their peculiar views, we will assume that there is an agent, and as many think a subtle fluid residing in a latent state as a component part of all substances, and called electricity. Every body in nature must, therefore, have upon this supposition one state in which the electricity may be said to be in equilibrium. By friction, and by many other causes, the electric equilibrium may be disturbed, and the agent set free from its combination, and by good conductors be carried away. This disturbed electric state of a body cannot, however, continue, for there is a never-ceasing effort between all particles of matter to retain, and restore when disturbed, the electric equilibrium.

The question, What is electricity? has never been, and perhaps never will be satisfactorily answered. Some persons have imagined it a fluid, others have called it an imponderable body, but what idea is attached to this designation we cannot possibly imagine. Professor Ritchie's remarks on this subject are very curious:—"The electric fluid' possesses one of the essential properties of ponderable matter. When a body is put in motion it will communicate a portion of its motion to other matter, but not without losing a corresponding quantity of its own motion. Hence agreeably to the experiments of Mr. Faraday, when the electricity of one wire is forced to induce electric polarity on that belonging to another wire, the momentum of the first suffers a corresponding reduction. Again, the motion of the electricity of a wire towards a state of polarity, will continue after the inducing cause has been removed, thus exhibiting in another point

of view, the same property of ponderable matter, viz. the inertia of matter, or in this case its tendency to continue in motion, after the impulse which first produced the motion has ceased.

"If these views be correct, we have no right to expect that bodies, at different temperatures, or differently electrified or magnetized, will have different weights, since in each of these states they contain exactly the same quantity of ponderable, improperly called imponderable matter.

"It is a well known fact that we receive a more powerful shock when electricity is being induced on the body, than when the induced electricity is returning to its natural state This is what might be expected from considering the energy and quantity of the exciting agents employed, these being either a powerful voltaic battery, or the immense quantity of electricity put in rapid motion in a large mass of soft iron."

Having now introduced the science of ordinary electricity, and explained the construction of the machine by which the electric fluid may be set free, in a state fit for experiment, the facts which have been ascertained concerning its transference, accumulation, and independent action upon matter, may be considered.

CONDUCTION OF ELECTRICITY.

requires no argument, nor any experiments in addition to those already mentioned, to prove that some substances transmit electricity more readily than others. But it is not an

easy task to determine the relative conducting power of substances; for those which, in their ordinary combination with other elementary principles, are most permeable to the electric fluid, may effectually resist its progress, when in an uncombined and pure state. There is an order in which all bodies might be arranged, beginning with the substance most permeable to the electric fluid, and terminating with that which evinces least of this power; but to draw a line of demarcation, or to say, this series comprises the conducting, and this the non-conducting bodies, is perfectly impossible. Time is required for the transmission of electrical influence from one substance to another;—in some instances the duration may be measured, in others it cannot. If a bunch of metallic threads be connected with the conductor of a machine, they will transmit the electricity so readily that a quadrant-electrometer, in contact with the conductor would not give evidence of the presence of electricity. But if glass threads be placed under the same circumstances, they will gradually exhibit the repulsion which always exists between bodies similarly electrified, and if a sudden communication be formed with the ground, they will as slowly collapse. Hence then it would appear that some bodies have a conducting power, inferior to others, and consequently require a longer period for the production of any effect. Many electricians have, we believe, considered the phenomenon of electrical conduction, as though it developed some peculiarity or election in the fluid itself, rather than a particular state of the body which receives the electrical influence. "The only difference" (between conductors and non-conductors,)

says Professor Leslie, "consists in the celerity with which the effect is produced, and were conductors properly classed, it would be found, in the descending range, that the velocity of transmission diminishes by insensible shades." We cannot, however, altogether coincide with this view of electrical conduction; for the celerity with which substances transmit the fluid is not the only difference between conductors and non-conductors, there are some substances which cannot be made to give a passage to electricity through any considerable length, there is in fact a limit to their conducting power.

In the second volume of Tilloch's Magazine, (1798,) an experiment is described by Mr. W. Wood, which, he thinks, proves the permeability of glass to the electricity of the common machine. He placed one of Cavallo's atmospherical electrometers upon a glass pedestal, and covered it with a thick glass receiver, so large, that there was a space of two inches between its sides, and the electrometer. A charged jar was then brought near the apparatus, and the balls instantly diverged. When the receiver was touched with the knob of the jar, the distance between the balls was doubled, but they collapsed as soon as the jar was removed.

We are at a loss to know how this experiment can be considered as a proof of the permeability of glass to electricity. If there had been a transmission of electricity, the pith balls would have been permanently diverged as in the common gold leaf electroscope. The effect is evidently to be traced to induction. This experiment might be repeated,

and when the effects are registered, the influence of a stream of electricity from a point should be ascertained.

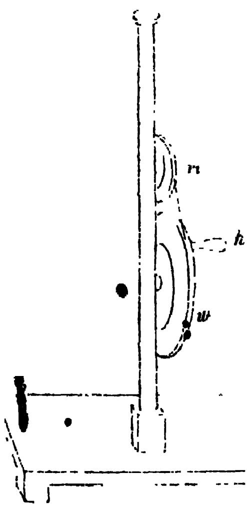
The magnitude of the conductor should also be carefully observed, for according to Professor Cummings' experiments, this has a great influence on the rate of transmission.

Many attempts have been made to ascertain the distance to which electricity may be conveyed by good conductors, and the time required in transmission. The accumulated electricity of a Leyden battery was once made to traverse a wire four miles in length; and an electric shock from a jar was at another time passed through one hundred and eighty of the French guards by the Abbe Nollet in the presence of the King. At the Carthusian convent, in Paris, the monks were formed into a line, which was more than a mile in length, each person being separated from his neighbour by an iron wire; but all the persons included in the circuit appeared to feel the shock at the same moment. From these and many similar experiments, it is evident, that the passage of electricity through good conductors is almost instantaneous, and that it may be transmitted to any distance, provided the conductor itself be sufficiently large to give the fluid an easy passage.

Mr. Talbot proposed some time since the following method of determining whether any appreciable time is required in the passage of electricity through a conductor "Let the greatest length of wire," he says, "that can be procured be disposed so, that the two extremities are brought very nearly

together. Let one end of the wire receive the spark from the machine, and the other end give it out again to any body which communicates with the earth. If the flashes of electric light on entering the wire, and leaving it after traversing its whole length, appear simultaneous to the eye, take a mirror mounted on a revolving axis, and place it in such a position that the mirror being at rest, the images of the two sparks may coincide or superpoise one another. This being effected let the observation be made through a fixed tube, placing the combined image exactly in the centre of the tube; then if the mirror be made to revolve with great speed, if any separation of the combined sparks into two take place, it will be a proof of the existence of an interval of time between them."

Fig. 62.



We have been accustomed to exhibit the instantaneous transmission of electricity by the momentary effect of the light which is produced when it passes from one substance to another, through an indifferent conductor.

In fig. 62, is represented an instrument admirably adapted for the exhibition of this phenomenon. *w* is a wheel turned by the handle *h*; this is connected by a cord with a multiplying wheel *m*. To the mul-

tiplying wheel, but on the opposite side of the upright, is attached a circular board on which the Newtonian colours are painted. The rapid rotation it receives from its connection with the multiplying wheel causes the colours to blend, and the surface consequently appears white. But if during the rotation a small jar be discharged before it, or a spark be produced in any other way, the whole series of colours may be for an instant observed.

It is not easy to explain why some bodies have the power of conducting electricity, and others resist its progress, nor is it our intention to describe the numerous theories which have been proposed to account for the fact. But it may not be improper to allude very briefly to one hypothesis by which it may be accounted for. Every substance has its own natural quantity of electricity, which it retains with a certain tenacity, and may, therefore, be considered as resisting the entrance of the fluid that seeks a passage through it, or over its surface. Accumulated electricity must, therefore, have, even under the most favourable circumstances, a force to overcome, before it can obtain a passage through the body with which it is brought in contact. Now it is possible that some substances may have a much more powerful attraction for their natural electricity than others, and if this be the case, the attraction of some may be sufficient to resist the influence of an external agent, and the force of cohesion be overcome, rather than the fixed association of the matter with its electricity.

This hypothesis may be illustrated by one experiment. Charge the conductor of an electrical machine, and bring

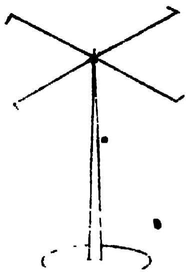
towards it, at what is technically called a striking distance, a brass knob, or any other conducting body, and the fluid will escape attended by a snap and a vivid spark. But in passing through the conductor of the machine, or the ball and the body of the person who holds it, no such phenomena are observed. What, it may be asked, is the cause of this difference. The electricity cannot pass from the prime conductor to any body beyond it without traversing a stratum of air, which is more or less a bad conductor, according to the quantity of aqueous vapour it may contain. Now the air, by the terms of the theory, holds its natural electricity with great tenacity, and offers considerable resistance to the passage of the extraneous fluid, and this resistance upon principles to be hereafter explained, is said to be sufficient to account for the production of luminous appearances.

The experiment just mentioned leads us at once to speak of the influence of points in the conduction of electricity. When a brass ball is brought near to the charged conductor of a machine, the electricity passes from one to the other attended by a sudden snap, and the evolution of light, but if a wire of the same metal terminating in a point, be brought in the same situation, neither of these effects is produced, the electric fluid is conducted quietly away, and the only evidence of the transmission is, that if the experiment be performed in a dark room, a small brush of feeble light may be observed at the point.

It will now be easy to explain why the metallic rods attached to buildings, for the purpose of defending them from the effects of lightning are always made to terminate in points. Franklin was the first philosopher who ascertained that lightning was an effect of atmospheric electricity, an agent which, according to our present information, differs in no particular from that obtained by friction. Having made this important discovery by raising a kite into the air, so constructed, as to draw the electricity of the clouds to the earth; he applied his discovery to the construction of a lightning conductor by which the presence of atmospherical electricity may be detected, and buildings defended from its destructive effects. From facts already mentioned, it will be evident that in the construction of a lightning conductor. there must be no interruption to the passage of the electricity,—or in other words, the metallic rod must pass through the building it is intended to protect, and enter the ground to some depth. If the continuity of the rod be any where broken, the most serious results will occur when electricity attempts to pass through it. The fluid losing its conducting substance must fly to that body which offers it the most ready transit, and if its progress should be resisted, will tear it asunder. There are many pretty experiments by which the influence of points may be exhibited, and especially those in which motion is obtained. Some of these we may mention.

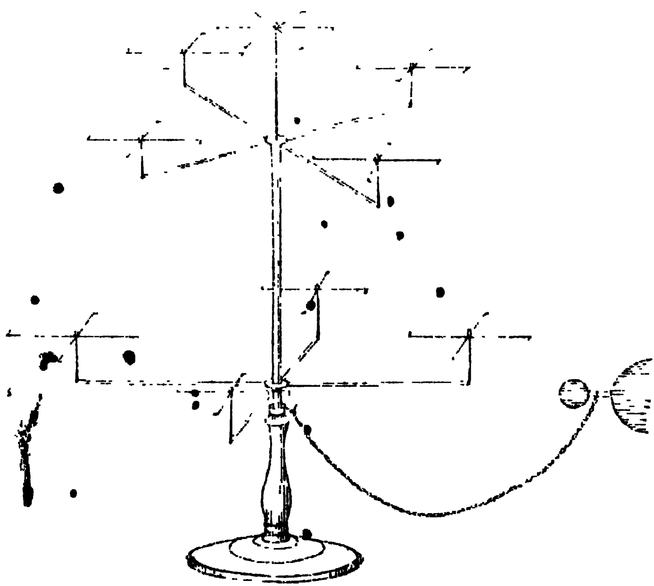
Let two thin wires *a a*, *b b*, fig. 63, be fixed at right angles to each other in a central cap, and let all the four arms terminate in points bent in the same direction. Place this

Fig. 63.



arrangement upon a stand, the lower part being formed of glass for insulation and the upper of metal terminating in a point on which the cross wires are to rotate. Connect the apparatus with the conductor of an electrical machine, and the wires will of course receive the free electricity; but as they terminate in points, the fluid will pass from them as readily as it is received. The current which is given off by each point meets, however, with the resistance of the air, and

Fig. 64.



a reaction is consequently produced, driving the whole arrangement in a direction opposite to that of the electric current. This effect may be exhibited in a much more imposing manner by the apparatus shown in fig. 64.

The same principle is exhibited in the electrical inclined plane. Two wires are stretched at a gentle inclination between four horizontal glass pillars. Upon these rests another wire having balls at its extremities, and carrying in its centre and at right angles to itself, two cross wires terminating in points. When the instrument is connected with the charged conductor, the electricity escapes from the points, causing the cross wires to roll up the plane, overcoming the force of gravity.

DISTRIBUTION.

But it may be here asked: In what manner is the free electricity developed by friction distributed? Does the electricity obtained from any substance depend on its mass, or merely on the amount of surface?

It is well known to every one who has been accustomed to make experiments with the electrical machine, that a hollow cylinder is capable of receiving and developing, as large an amount of the fluid as a solid of the same size. For this reason the conductor of the machine is always made hollow. By mathematical investigations, Coulomb, Poisson, and Ivory, have ascertained the same fact, so that on this question experiment and analysis agree. We may therefore conclude that the free electricity is not developed throughout

the substance of a charged body, and another question now arises;—Is it only on the surface?

The early electricians were not inattentive to this enquiry. To determine the question, Watson covered the surface of a metallic rod with a thin coating of wax, and found that its conducting power was not injured; from which he concludes that the electricity is not developed on the surface of bodies. M. le Monnier made some experiments for the same purpose about the same time. He proved that bodies of equal size and form, one being solid, and the other the thinnest possible shell of the same material, could receive the same charge, and therefore concludes that, if the electricity be not developed on the surface, it must be so near that we may speak of it as residing on the surface of bodies.

Coulomb investigated this subject with great care, and proved the truth of M. le Monnier's opinions. He took an elliptical metallic body, and cut in it small apertures or pits, some of them half an inch deep, others not more than one-tenth of an inch. When the body was electrified, he introduced a small instrument which he calls a proof plane to the bottom of these pits, testing the electricity by a torsion electrometer. The proof plane consists of a small disc of gold paper fastened to a thin cylinder of gum lac. When the disc is introduced into the pit, it will of course abstract its electricity, the presence of which will be shown by bringing it to the electrometer. The experiments that were made by Coulomb with this instrument decisively proved that electricity was only distributed over the surface of bodies, for the pits were not in an electrified state.

Biot has invented two very interesting experiments to illustrate this fact. Having provided himself with a spheroid of some conducting substance, he suspended it by a thread, so as to perfectly insulate it. Over this body were fitted two pieces of gold paper or tin foil, with insulating handles of gum lac, both being movable, and yet made to fit accurately. The ball was then electrified, and afterwards the caps were carefully applied. Upon their removal it was found that the whole of the electricity had been abstracted from the spheriod, so that it could not affect the most delicate electrometer, while the two caps were proved to possess the same quantity of electricity as had been first communicated to the spheriod itself.

The same fact is proved by another experiment,—a light tin cylinder was supported horizontally on glass legs, for insulation, and so fixed as to be easily moved round by a handle at one end. To the opposite end two pith balls were attached, opening when the cylinder was electrified, and collapsing as the fluid was dissipated. Round the centre of the cylinder a piece of tin foil was fixed with a flap which could be wound round at pleasure. When the tin foil was coiled on the cylinder, and the instrument charged with electricity the pith balls opened, but as it unwound itself, the balls collapsed. The cause of this was evidently the distribution of the electricity on a larger surface;—that presented by the flap of tin foil.

DISSIPATION.

When a substance is charged with electricity, however highly it may be excited, the restoration of equilibrium is soon effected—this process is called Dissipation. Thus, if we charge two pith balls with the same electricity, taking care to ensure a perfect insulation, they will diverge, but in a few moments they, without the application of any conducting body, begin to collapse, and the electricity will be entirely lost.

To ascertain the various causes which may produce the dissipation of electricity is of the greatest importance, as giving an opportunity of avoiding, or correcting the sources of many failures in our electrical experiments. The electrical equilibrium of a body is very readily disturbed, but it is as quickly restored, an effect that may be attributed to one or all of the four following causes: first, the imperfect insulating power of the best non-conductors; secondly, the deposition of moisture on the insulating body; thirdly, the contact of successive particles of air; and lastly, the existence of points on the surface of the excited substance.

The difference between the conducting powers of substances has reference, as we have already explained, to time; here are some which give it an instantaneous passage, and others require a greater or less duration. No substance is so perfectly impermeable to the electric fluid, but it may after the lapse of time exercise the power of conduction. The dissipation under ordinary circumstances is, however, to be much more attributed to the deposition of moisture on the

insulating body. The vapour of the atmosphere is condensed, and forming a thin coating on the insulating surface gives a very ready conduction to the electric fluid. Nearly all the failures to which electricians are subject in public theatres, may be traced to this cause, and there is no means of entirely preventing it, although a coating of gum is found to be of some service. The difficulty of making a successful series of experiments before a large audience may be imagined from the appearance frequently presented on the glass of windows by the condensation of the vapour upon them. The same process is of course effected on all the vitreous bodies used for insulation in electrical apparatus.

The continued contact of particles of air, must also be a means of discharging the electricity of excited bodies. It is one of the first principles of the science that an excited substance attracts to itself all the light unelectrified bodies around it, and that it communicates to them the same state of electricity, by which repulsion is occasioned. This effect must be produced upon the particles of air, which are severally attracted to the excited electric or conductor, and after receiving the charge are repelled, giving room for the contact of other particles. The atmosphere may, therefore, be properly called a slow, but constant discharger of electricity.

The great readiness with which electricity is carried away by points, is proved by the experiments already described. If such points should exist upon any substance, it will be impossible to give it a permanent charge; or if they should be few in comparison to the size of the body, the charge will be small and soon expended. In this way dust prevents the

accumulation of electricity. Every one who is accustomed to perform electrical experiments, must know that dust is not less active than moisture in preventing the action of his apparatus.

These few practical observations on the causes of dissipation, will it is hoped be of some use to the young electrician, as warning him of those causes most likely to derange his experiments, and prevent the results he would otherwise obtain.

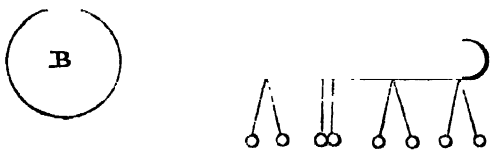
INDUCTION AND ACCUMULATION.

Hitherto we have considered the electrical states of bodies, as affected by only two causes, excitement and conduction, but there is another class of phenomena arising from an agency called induction. This is a subject of the greatest importance; one which must be thoroughly understood before it will be possible to investigate many of the most interesting branches of electrical science.

When a substance is charged with electricity, or has its electrical condition disturbed, it will produce an opposite electrical state in that portion of a body which is brought near it, supposing there is no positive contact. Thus if we bring a positively electrified substance near to one in its natural state, that surface which is nearest to the excited body, will be negatively electrified, and of course that most distant will be in an opposite condition, that is, in the same state as the electric. This fact may be proved in the following manner.

Let B, fig. 65, be any substance charged with positive electricity, a metallic globe for instance properly insulated, and N P a metallic cylinder (supported on a glass rod,), to which pith balls are suspended, and by their action evidence is given of the electrified state. As soon as the cylinder is brought near the excited globe, the pith balls will diverge, the divergence decreasing from the two extremities towards the centre. By testing the electricity of the balls, it will be discovered that those nearest the excited body are negative, and those most distant positive.

Fig. 65.



To prove that the effect is altogether independent of conduction, a non-conducting substance may be brought between the excited globe and the cylinder, and the same phenomena will be developed. Let the conductor of an electrical machine be excited, and the metallic cylinder with its pith ball electroscopes be placed near it, the divergence already spoken of will be produced. If a plate of glass be now introduced between the electric and the cylinder, no alteratio in the state of the pith balls will be perceptible.

We may also show by experiment the influence of induce electricity upon an excited body. Take a metallic globe, which is furnished with electroscopes on its opposite sur-

faces, insulate and charge it. The electricity will of course be equally distributed over the whole surface, and the electroscopes will diverge equally. But bring near to it a conducting body, and the balls most distant from that body will begin to collapse, while those nearest to it will diverge still more, thus showing experimentally that the electricity suffers change by the approximation of the conducting body. In this, and in all other experiments before mentioned, there has been no positive transfer; as will be evident by removing the charged body, which will instantly cause the balls to present the same appearance as they had before it was brought into proximity with the conductor.

The most important application of the principle of induction is in the accumulation of electricity, a subject to which we must now direct the attention of the reader.

Let two metallic discs be placed one above the other, and separated by some non-conducting substance, as a stratum of air, or a glass plate. Let the upper plate be connected with the prime conductor of the machine, and the lower be insulated by being placed on a stool with glass legs. Charge the plate that is in contact with the conductor of the machine. On the principle of induction the electricity contained in the lower plate will be repelled by that communicated to the upper, and will quit the higher surface, and take to the lower. But now establish a connection between the lower plate and the ground, and all the accumulated fluid in the lower surface of the plate will be conducted away, and the whole plate become negative. A larger quantity of electricity is now collected by the upper plate, as may be proved by placing a quadrant

electrometer on the prime conductor, for as soon as the lower plate is made to communicate with the ground by means of the wire, it falls, showing that the electricity of the prime conductor is decreased. The electrifying machine being put into action, the electrometer is again raised. Hence then it will appear that electricity may be accumulated by induction.

Electricity may be more conveniently collected by using a glass plate, coated on each side with tinfoil; but in performing this experiment it is necessary to leave a margin of the glass uncovered, so as to prevent any transfer of the fluid from one side to the other. The principle of action in this experiment is the same as that already described. One surface is connected with the earth, the other is brought near to an excited body from which it receives its changed electric state.

But although we may very easily exhibit all the phenomena of induction by a plate partly covered on both sides with tin foil, a jar or cylinder is a still more convenient form and especially when it is necessary to accumulate the electricity in large quantities, or to have the same agent in a state of great intensity. A glass vessel thus prepared is called a Leyden jar, because first used by Kleish and others, who resided at Leyden. As commonly constructed, it consists of a glass jar coated on its exterior and interior surfaces, a sufficient space at the upper part or lip being left to prevent spontaneous discharge, which might happen, if the surface were not separated by a sufficient interval. The charge of electricity is conveyed to the interior by means of a brass

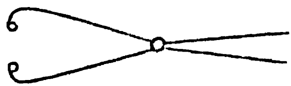
rod, to one end of which is affixed a chain touching the interior coating, and to the other a metallic ball. The outer coating is made to communicate with the ground, for without this precaution the jar could not be charged, as may be proved by connecting the jar, when placed on an insulating stand, with an excited conductor. But when the jar is thus insulated, bring the knuckle to the exterior coating, the interior being in connection with the machine, and a succession of sparks will be obtained in the same manner as between the ball of the interior coating and the conductor of the machine.

But if instead of touching the exterior coating, we bring the knob of a second jar into contact with it, the exterior of the second jar being connected with the ground, then the interior coating of the second will be charged with that driven off from the exterior coating of the first. In this way any number of jars may be charged, if they be only insulated; the exterior coating of the last jar having a communication with the ground. This communication with the ground may also be made, by holding the jar in the hand, for the human body is a conductor.

To discharge a jar, or in other words to restore electric equilibrium, it is only necessary to unite the two unequally electrified surfaces. For the purpose of making this communication between the two surfaces of any body, that has its electric condition disturbed, an instrument, called the discharging rod, fig. 66, is generally used. It consists of a bent wire fixed in a glass handle, like a pair of compasses, each end being furnished with a brass knob. When one knob is

made to communicate with one side of an electrified body, and the other with the opposite side, the positive electricity rushes towards the negative, and re-establishes the equilibrium.

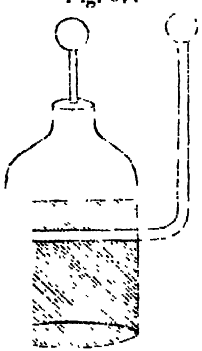
Fig. 66.



The following facts and experiments will still further illustrate the principle and action of the Leyden jar.

1. The exterior and interior coatings are oppositely electrified; if the interior be positive, the exterior must be negative, and the reverse. This fact is obvious, from the remarks that have already been made upon the principle of accumulation by induction. But to prove the fact by experiment, attach to the outside coating of a Leyden jar, fig. 67, a metallic band and a vertical wire, rising to the height of the wire that passes into the interior, and furnish the end with a knob. If the jar be now charged, and insulated, a pith ball or bird, brought between the two knobs, will begin a vibratory motion, being alternately attracted by each, until the jar is entirely discharged.

Fig. 67.



2. The charge communicated to a jar will greatly depend upon its thickness, for the induction decreases as the distance between the two bodies or surfaces increases. Hence

it is that a thick jar will never receive so good a charge as a thin one.

3. The presence of the coatings is not absolutely necessary for the charge or discharge of the surfaces. Let us for instance charge a jar with moveable coatings,—remove the coatings, and the jar may be gradually discharged by successively forming the contact between the surfaces; but as there is no common medium for the simultaneous transference of the electricity of the different parts of the surfaces, it cannot be discharged at once. That the coating acts in no other manner than as a conductor, may be readily proved by charging a jar with one pair of moveable coatings, and then removing them and substituting others. If the two surfaces be connected by a discharging rod when this has been done, it will be found that the glass retained the fluid, when the coating was removed, and that but little of the charge was lost by the experiment.

But a jar may also be charged without coatings. Holding it by its exterior surface, pass the interior before a ball connected with the prime conductor of the machine, so that every part may be in a situation to receive the fluid. Then apply the coatings, and the jar may be discharged.

In the use of the Leyden jar great care must be taken to avoid a spontaneous discharge. There are two things which render this not only possible but probable.

We have stated that a thin jar is capable of receiving a better charge than a thick one. But there is a limit to this rule, for no substance is so bad a conductor of electricity as to be incapable of transmitting it for a short distance. It

does sometimes happen that a jar receives a higher charge than it can bear, and the electricity forces for itself a passage through the substance of the glass.

When the charge is great the electricity may pass round the edges of the glass, from one coating to the other, the liability to which is increased by the deposition of moisture on the jar, which establishes a ready conduction. The latter must be carefully avoided, and it will be best done by covering the uncoated part of the glass with a layer of sealing wax or resinous varnish.

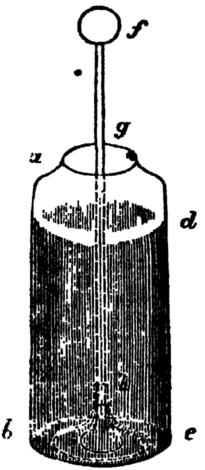
By uniting a number of jars electricity may be accumulated with an intensity proportionate to the number of vessels and the square feet in each jar. Such a series is called an electrical battery. To form a battery it is only necessary to establish a communication by metal rods between the interior coatings, and to connect the exterior by placing them in a box, the bottom of which is covered with tin-foil or some other conductor. With such an apparatus we possess the power of accumulating a most destructive agent, and great care is therefore required in its use.

MR. HARRIS'S LEYDEN JAR.

Mr. Snow Harris introduced a modification of the Leyden jar, which he considers very preferable to any other kind. A glass jar, *a b*, fig. 68, has in this, as in all othercases, both the exterior and interior surfaces, covered with tin foil to a certain height. The jar is made without a cover, and

the charge is communicated to the interior by a copper tube *f g h* to the upper end of which a ball of baked wood *f* is attached. At the bottom of the glass is fixed a convenient foot covered with paper, and through this the rod is passed and brought into contact with the tin foil. The foot is intended to keep the tube in its place.

Fig. 68.

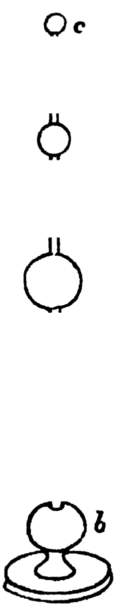


"These jars," says Mr. Harris, "when employed either separately or collectively, are placed on a conducting base, sustained by short columns of glass, or some other insulating substance, so that the whole can be insulated when required; and, for the purpose of allowing them to be charged and discharged with precision; they are connected with what may be considered as two centres of action.

The first of these consists of a brass ball *a*, fig. 69, which slides with friction on a metallic rod *c b*, so as to admit of its being adjusted to any required altitude. It has a number of small holes drilled in its circumference, for receiving the points of the connecting rods of the jars. The rod which sustains this ball, is either insulated on a separate foot, and connected with the conductor of the machine, or is otherwise inserted directly into it. The second centre consists of a large ball of metal, attached to a firm foot, and placed on

the same conducting base as the jars, so as to have perfect connexion with it."

Fig. 69.

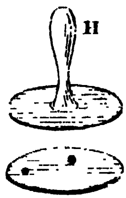


In a paper recently read before the Electrical Society, Mr. Sturgeon explains the manner in which he has been for a long time, accustomed to coat his jars. In discharging jars fully electrified, accidents frequently happen and the glass is cracked. The trouble and expense resulting from this induced him to make a few experiments to determine the cause, and if possible to provide a remedy. He soon found that the cracks were generally produced on or near the edge of the tin foil. But without tracing the experimental course he adopted, it may be sufficient to state that small pieces or bands of tin foil, carried from the edge of the inner coating to the cover, which is on the inner surface lined with the same metal, has been found sufficient to prevent the mischief. From this statement, therefore, it would appear that if the whole of the interior of a jar be coated, a sufficient striking distance between the positive and negative surfaces being preserved, the glass will be less likely to break from the suddenness of the discharge, than when constructed in the usual way.

THE ELECTROPHORUS.

We shall now close our remarks on the induction and accumulation of electricity by a short account of the electrophorus, one of the most ingenious and useful electrical instruments ever invented. H, fig. 70, is a glass handle fastened to a metallic plate A, which is called the cover, B is a metallic dish, into which is poured, when in a liquid state, a compound, consisting of equal parts of shell-lac, resin, and Venice turpentine. To put the instrument in action rub the lower or resinous plate, with a piece of dry fur or cat's skin, and it will be electrified negatively. Now bring the other plate upon it, and when in that position touch the upper surface with the finger. If the metallic plate be then removed, and a brass ball or the hand of the experimenter be brought near it, a spark will be observed. When the metallic plate is again brought to the resin and touched in the same manner, a similar effect will be produced, and this may be repeated many times. Hence then it must appear that the effect is not produced by conduction, for if it were the electricity of the resinous substance would be soon exhausted, and as the upper plate must be connected with the ground, either by the finger or otherwise, it must appear probable that some effect is produced on the metal by proximity to the excited body. This is really the case, the effect may be accounted for on the principles of induction, explained in the first part of this section.

Fig. 70.



There are few instruments more generally useful than the Electrophorus. It will continue in a state of excitement for months, and even years, and if in an unexcited state may be soon put in action. To the chemist it is invaluable, as affording a ready means of detonating gases, and performing other experiments. It may also sometimes supply the place of an electrical machine, for with it Leyden jars may be charged, and nearly all the ordinary experiments are consequently under the control of a person who has only an electrophorus as a source of electricity.

The sketch we have given of the principles of electrical induction, and of the method by which the fluid may be accumulated, will, it is hoped, be sufficient to direct the student in his investigations. Our aim has not been to introduce new enquiries, but, to explain those which are known to electricians, and universally acknowledged as the elements of this important branch of philosophical knowledge.

ELECTROSCOPES AND ELECTROMETERS.

We must now proceed to the explanation of some of the most important instruments employed by electricians for detecting the presence, ascertaining the character, and measuring the intensity of ordinary electricity. Those instruments which merely indicate the presence of electricity, and offer an opportunity of detecting its character, are called electroscopes, those which measure its intensity are called electrometers.

The most simple kind of electrometer is that in which two pith balls are suspended from silk threads, or any other non-conducting substance. When these balls are charged with electricity, they repel each other, giving evidence of the change of state. They also enable us to determine the nature of the electricity, for by bringing an excited stick of resin or glass near to them when charged, they will be repelled or attracted according to their state.

CAVALLO'S ELECTROSCOPES.

Mr. Cavallo constructed an instrument of this kind in a very portable manner. Two pith balls attached to silk threads were fixed in a cork, or a piece of dry wood, fitting a tube open at one end. When the instrument was not in use, the electroscope was placed in the tube, and thus defended from injury; when required for experiment, the wood or cork was placed in the open end of the tube, which was, in fact, a convenient handle.

There are various modifications of this instrument, which may be constructed so as to suit the fancy of either the instrument-maker or the purchaser. To describe these varieties is not necessary, but it may be mentioned that Cavallo employed the pith balls in a manner different from that already described for the purpose of detecting the electrical condition of atmospheres. We have recently had occasion to use the instrument, and as it is one easily made and employed by every reader, it may be desirable to explain

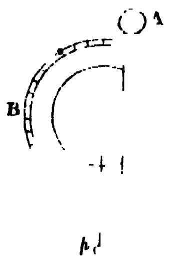
its construction. To a large cork ball a pair of small pith balls are suspended by a very fine silk thread. The cork ball is attached to one end of a glass tube, and the other end of the tube is so fitted to a wooden rod coated with sealing wax, as to be removed at pleasure for the convenience of transit. A fine metallic thread is also attached to the cork ball, which gives the instrument the appearance of a fishing rod; this thread however is not fixed to the cork, but the end is pushed into it, and may be drawn away at pleasure. The object of the instrument is to detect the electrical state of any atmosphere,—for instance, the atmosphere of a crowded room. The wire being fixed in the cork ball the electroscope is introduced from an adjoining apartment. So long as the metallic string is held in the hand, the balls cannot receive any permanent electrical change, as the fluid is carried away to the body of the experimenter. By a slight pull the metallic thread is separated from the ball, and the electroscope is insulated; and by the effects of excited wax or glass upon it the electricity of the atmosphere is determined.

HENLEY'S QUADRANT ELECTROMETER.

No electrometer is more generally useful than that invented by Mr. Henley, and called by his name. It is represented in fig. 71. A D is a wooden upright made very smooth, and generally polished. B is an ivory semicircle, the lower quadrant being divided into ninety equal parts or degrees. To the point C, which is the centre of the semi-

circle a thin piece of cane is attached, capable of moving round the graduated arc. To the end of this cane a pith

Fig. 71.



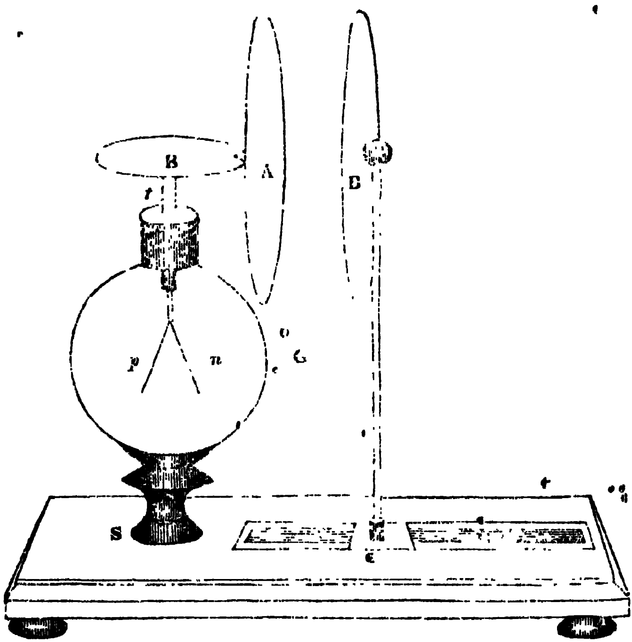
ball *p* is fixed. Without this instrument no very extensive course of experiments can be performed, and we shall best explain its action by supposing it to be attached to a Leyden jar. The interior coating and the upright A D, being in conducting communication, the instrument itself must be charged with the same electricity as the Leyden jar. If this be true the pith ball *p*, and the stick A D, will be similarly electrified, and exhibit the phenomenon of repulsion; the arm C *p* rising in proportion to the intensity of the accumulated fluid.

GOLD-LEAF ELECTROSCOPE.

The Gold-Leaf Electroscope, fig. 72, is an exceedingly delicate and useful instrument. That arrangement of it represented in the diagram is made by Mr. Clarke of the Lowther Arcade. It acts upon precisely the same principle as the pith ball electroscope of Cavallo, but is far more delicate, and suited to the examination of electricity of the lowest intensity. However weak may be the disturbance, it is sufficient to detect the change of state, and especially so when constructed in the manner represented in the accompanying figure. G is a glass globe fixed at one end to a stand S. On

the opposite end is fitted a cap with an aperture through which the tube *t* passes. B is a metallic plate with which the glass tube *t* is connected. From the metallic plate is carried a wire having at its termination two slips *p n*, of gold-leaf. A B represent the condensing plates. The apparatus is fixed upon a mahogany stand, and one arm of the condenser is so attached that it may be brought at pleasure nearer to, or farther from, the plate fixed to the electroscope.

Fig. 72.



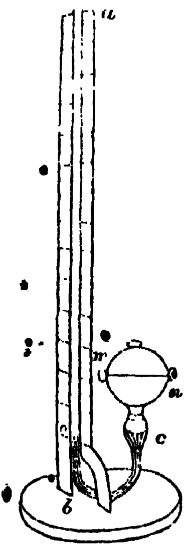
We have frequently had occasion to use, in an extensive

course of experiments, gold-leaf electroscopes; but none have been so delicate as that constructed by Mr. Clarke. In nearly all arrangements of this sort too much brass work is introduced in the cap, dissipating the fluid, and in many cases absolutely destroying the effect.

HARRIS'S ELECTROMETER.

We may here mention an exceedingly useful electrometer, invented by Mr. Harris to measure the effect of a given accumulation. The instrument is very simple, and is in fact little more than an air thermometer with a metallic wire passed through the bulb. It is represented in fig. 73: *a b c* is a glass tube, the interior diameter of which is about one-tenth of an inch, bent at one end, and attached to a glass bulb about three inches in diameter. The tube terminates in a cup *c*, into which some coloured spirit is placed: *m n* is a wire passing through the centre of a bulb.

Fig. 73.



The following method of fixing it was adopted by Mr. Harris:—"two flanches of brass, with projecting screws and shoulders, are cemented in and over the holes drilled in the glass, the wire is passed directly through the bulb by means of corresponding holes in these

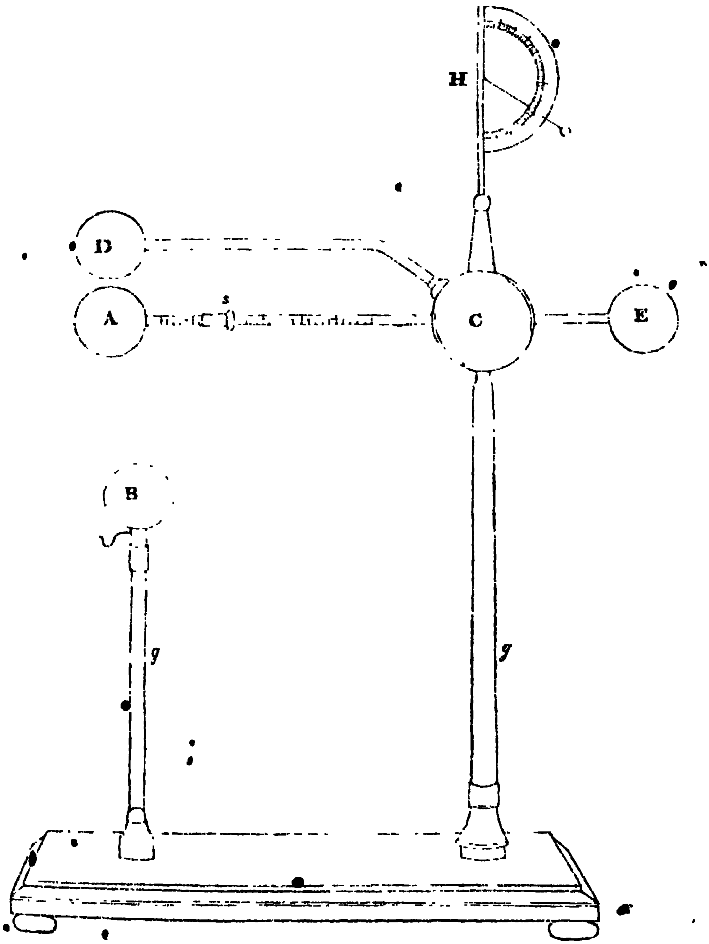
flanches, and being gently put on the stretch, is secured by short metallic or wood pegs by which it is slightly compressed, and retained in its situation. Both the pegs and extremities of the wire project a little for the convenience of removal, and thus wires of various kinds, and of different diameters, may be easily substituted. The whole is rendered air tight by means of small balls of brass, which are made flat at one extremity, and screwed on the projecting parts of the flanches against a collar of leather." The vertical part *a b* of the glass tube is supported by a graduated scale attached to a convenient base. The fluid is so adjusted that it may rise to exactly the lowest graduation on the scale which is called zero. When accumulated electricity is passed through the wire, the air in the bulb is acted upon, and the liquid is forced up the tube. The force of the explosion is estimated by the effect produced on the liquid, and this method of determining, as the inventor has stated, the effects of electrical explosions by their actions on metals, is much to be preferred to that in which the fusion of metallic wires, is made the means of calculation. Platinum is the metal best adapted for use in this instrument, as it is easily acted on, and not liable to oxidation.

CUTHBERTSON'S BALANCE ELECTROMETER.

Mr. Cuthbertson's Balance Electrometer, fig. 74, was once commonly used by electricians, but in consequence of the

very indifferent manner in which it has been constructed, is now seldom employed. When the instrument-maker will

Fig. 74.



take a little pains in forming it, there is no difficulty in obtaining accurate results. *g g* are glass pillars supported by a mahogany stand. C is a brass ball, into which is fixed an arm carrying the ball D. A and E are metallic balls at the ends of a lever, and moving on a knife edge in the centre of the hollow ball C. B is another brass ball insulated by the glass rod *g*. The arm connecting A and C is made of glass, and graduated: *s* is a slide, and by moving it towards A or C, the charge may be regulated. The action of the instrument will be best exhibited by supposing the ball B to be connected with the exterior coating of a Leyden jar, and the ball D or C, which are in metallic connection, with the interior. As soon as we begin to charge the jar there will commence a repulsion between D and A, and an attraction between A and B, and at a certain point it will be sufficient to overcome the weight by which its fall is resisted, and striking upon B will discharge the jar. A greater charge is obtained by moving *s* nearer to C, the centre of motion. H is a quadrant electrometer, placed at the top of the instrument to give evidence when the charge is being communicated, and the degree of intensity.

VON HAUCH'S DISCHARGING ELECTROMETER.

In the Transactions of the Royal Society of Copenhagen for the year 1799, we find a paper by Von Hauch describing an improved discharging electrometer of his invention. He complains of Lane's discharging electrometer, and Henley's

general discharger, because they act by a spontaneous discharge of electricity; and he considers all others imperfect for the same reason, as they are either constructed on a similar principle, or are so made that the conducting body is placed between two electric atmospheres. In the former case, the accuracy of experiments must depend on the conducting power of the atmosphere at the time, and in the latter upon the dexterity of the person who is making the experiment.

Von Hauch's Electrometer is constructed on the same principle as one previously invented by Brooks, namely, that of a comparison of the repulsive power of electricity between two bodies of a given size and known weight. The advantages, which he supposes to be possessed by his instrument over that by Mr. Brooks are, that neither the pressure of the atmosphere, nor friction, have any influence on it.

The instrument is represented in fig. 75, *m* and *n* are two massy pillars of glass, fixed in an upright position on a mahogany stand *o p*, which is about twelve inches in length and four in width. G G are brass rings covered with some resinous substance, and into them is screwed forks K, of tempered steel. E is a brass rod and ball screwed into the ring G: the ball is about an inch in diameter, and the rod and ball are about four and a half inches in length. A B is a delicate beam, the arms of which are of unequal length, turning on a knife edge of the fork K. The short arm is of brass, and is furnished with a ball B, of precisely the same size as the ball E. The long arm is formed of glass, covered with copal varnish, and terminates in an ivory ball A, which is furnished with a hook R, supporting an ivory scale H. The

beam is about seventeen inches in length, and the short arm, which is divided into forty-five parts, equivalent to grains, is about one-third of the whole length.

C D is a beam constructed and suspended in the same manner as A B. The long arm, which is furnished with a ball D, is divided into thirty parts, corresponding to grains; and the short glass arm terminates in a curved plate C: this beam is about eleven inches in length.

The brass ring Q, on the short arm of the longer beam, is so formed as to move over the rod, and shows the number of grains, that must be placed in the small scale to restore equilibrium. The moveable ring S, on the longer arm of the lower beam, also shows in grains, by its distance from the point of suspension, the power that would be required to overcome the preponderance of the other arm.

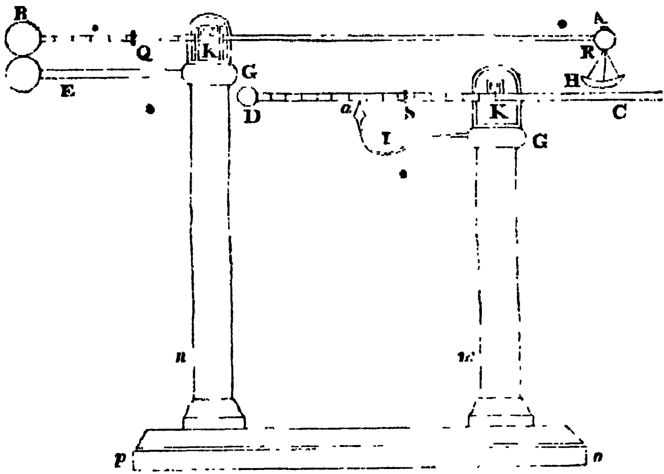
The power necessary for this purpose, says the author, will be found, if the scale H, which weighs exactly fourteen grains, be suffered to rest on the glass plate C, and the ring S be pushed forward till both arms of the beam are in equilibrium.

The balls B and E are just in contact. The ball D is four lines distant from the ring G, and the distance between the scale H, and the plate C, is exactly two lines. In each of the rings G G a small hole is formed so as to connect them with the two coatings of a Leyden jar. I is a brass wire with an ivory point *a* to support the beam C D.

We may now explain the action of the instrument. If A B be connected with the external coating of a Leyden jar, and C D with the internal; the two balls B and E will be

charged with electricity of the same name, and a repulsion will consequently be produced between them. Now as the

Fig. 75.



arm B ascends, the arm A descends, and being twice as long, must pass over double the space, and resting on the arm C, causes it to fall, and the arm D to rise; and as soon as the ball touches the ring G the two sides of the jar are connected, and the electricity is discharged. It will, however, be evident to the reader, that there is not only a repulsive power between the similarly electrified substances B E, but also an attraction between the dissimilarly electrified bodies D G, the contact of which discharges the jar. To prevent this, the attraction between D and G must be made less than the repulsion between B and E. For this purpose, says the

author, the ring S must always be removed two divisions farther on C D towards D, than the ring Q is shifted on A B towards B. If, for example, an electric force were required equal to eight grains, according to this electrometer, the ring Q must be removed to the point eight, and the ring S to the point ten. The repulsive power will then repel the balls B and E before G is in a condition to attract the ball D, as a power of two grains would be necessary for this purpose beside that of the eight already in action.

Von Hauch recommends his instrument as preferable to all other Discharging Electrometers, as being exceedingly simple in its construction, and as being made at a very small expense:—the want of these two important requisites we consider to be among the greatest objections to its general use.

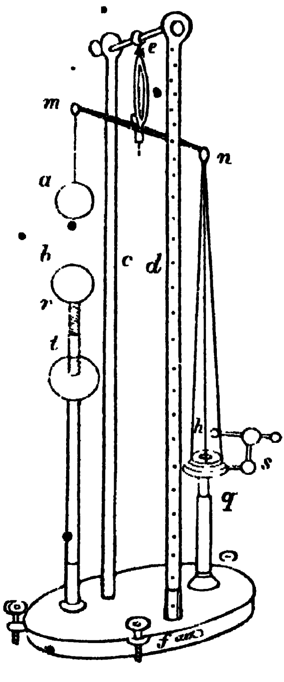
HARRIS'S ELECTRICAL BALANCE.

Among the electrometers we may also place Mr. Harris's Electrical Balance, an instrument invented for investigating the attractive force of accumulated electricity. The following is his own description of the instrument.

"The beam *m n*, fig. 76, is sustained in the required position, between two vertical rods of glass *c d*; a covered wire indicated by the dotted line passes through one of these, and connects it with the negative coating. From one of the arms *m*, a hollow gilded ball of wood *a*, is suspended by a metallic thread; this ball is about two inches in diameter and weighs about 160 grains. From the opposite arm is

suspended a light brass pan *h*, by means of silk lines in the usual way:—in this pan is placed as much additional weight as is requisite to balance the ball just mentioned; and to put the whole mass in a state of equilibrium. The attractive force of the accumulation is caused to act directly on the suspended ball *a*, by means of an insulated ball of brass *b*, of the same dimensions, which is fixed directly under it, and is connected with the positive coating: it is so placed that it can be depressed from contact with the suspended ball through given distances, by means of a cylindrical slide *r*, to which it is attached, and a socket *t*, the slide *r*, has a scale engraved on it, divided into twentieths of an inch, and is supported on a glass pillar by means of a varnished ball of baked wood, in which the socket is fixed, and through which the connexion with the positive coating passes.

Fig. 76.



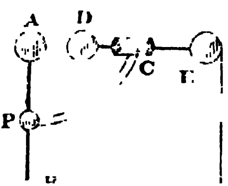
"It will be immediately perceived that in this arrangement the attractive force acts directly between the balls *a* and *b*, and it can therefore be measured under given conditions by weights, placed in the pan *h*, suspended from the opposite

arm of the beam. The pan is allowed to rest on a small circular support *q*, the elevation of which can be changed so as to accommodate it to the horizontal position of the beam, and check any oscillation: there is also a small stop *s*, inserted in this stand, which projects over the pan, and prevents the further descent of the beam, after the equilibrium is destroyed; without which the explosion would pass, and destroy the gilding of the ball."

LANE'S ELECTROMETER.

The electrometer, fig. 76, is a very useful, and at the same time a very easily constructed instrument. It is used for the purpose of discharging jars and batteries, and at the same time of regulating the intensity of the charge. A is the ball connected wtth the interior coating of a Leyden jar, and A B the metallic stem. D is a brass ball, and C a spring tube, through which the metallic rod D E slides. The curved glass rod PC insulates DE, and as will be presently seen prevents the passage of the electric fluid from one surface to the other of a Leyden jar. The ball A is, as already stated, supposed to be in metallic contact with the charged interior coating of a jar. E G is a chain in contact with the exterior coating, and hence it will be evident that A and D are oppositely electrified, and

Fig. 76.



represent the electric states of the two surfaces. To discharge a jar, or in other words to restore the equilibrium, the electricity must force its way from A to D, which is called the striking distance, and the intensity of the charge may, therefore, be varied by increasing or decreasing that distance. In using this, and indeed all electrometers, great care must be taken to avoid those sources of dissipation spoken of in a former part of this chapter. Dust upon the brass work, or moisture on the glass, will certainly prevent the action of the instrument.

There are few philosophical instrument makers who take sufficient care in the construction of electrometers and electroscopes; or in their electrical instruments generally. Perhaps we have little reason to expect they should, for their object is to sell and make money, and to this science is made subservient. When young persons begin the study of physics, they are frequently seized with so great an anxiety to possess what they consider the necessary apparatus for experiment that they immediately resolve on the purchase, and trusting themselves in the hands of some well known manufacturer, purchase not only what they think is wanted, but also what is recommended as necessary. Thus provided with instruments, they commence in earnest the performance of experiments, but to their great mortification fail in almost every thing they try, and the failure is at first attributed to a want of skill, but as their information increases, they discover that the instruments have been made to please the eye and not to exhibit scientific facts.

ELECTRICAL LIGHT.

When an Electrical machine is put in action, a series of beautiful sparks will be seen flying from the machine to the hand, or to any other conducting substance brought near it, A Leyden Jar when charged from the machine, is filled as it were by successive quantities, each portion being attended with a momentary flash of light. This light differs but little from that produced by the solar rays, or that obtained by combustible bodies, and may be readily decomposed by a prism in a dark room.

The colour of the electric spark is not always the same, it is generally white, when the electricity is passed from, and received by metals, but if it should be made to fall upon the surface of water, it will be red, and when received by the human body green. The alteration of distance between the excited and conducting body, will also alter the colour of the spark: this may, perhaps, be accounted for, from a variation in the resistance offered by the atmosphere. These are the changes in the luminous appearance produced by an alteration of substance and distance.

If an arrangement be adopted, by which an alteration in the density of the medium may be obtained, the distance remaining the same, the spark will be white as long as the common atmospheric pressure is maintained. But if the density of the air be diminished, the white light gradually changes to a violet tint. This appearance may be accounted for on the supposition that electricity is transmitted from the

one ball to the other, in an exhausted receiver, before it has attained the same degree of intensity, as it had under the common pressure of the atmosphere.

There is an experiment worthy of notice as tending to illustrate this branch of our subject. If a glass tube, two or three inches in diameter be connected with the prime conductor by a copper wire, the wire entering the tube about two or three inches, no electrical light will be at first produced by setting the machine in action, but if the tube be fixed to an air pump, and gradually exhausted, the electrical light will appear, becoming more and more diffused as the exhaustion proceeds.

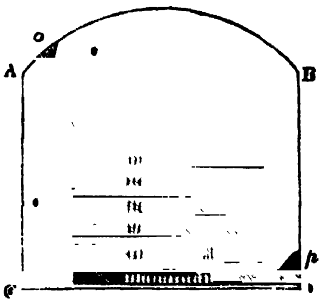
Many interesting experiments may be made to exhibit the luminous effects of electricity in motion. We will mention a few, which may be easily performed by any of our readers who have a small electrical apparatus.

When electricity passes from a good to a bad conductor, light is always given out. This fact has been applied in the construction of an interesting apparatus, for the exhibition of luminous appearances. Take a plate of glass and cover the centre of it with tin foil. Cut away portions of the metal so as to form a device, a letter, or a word. At all those parts where the glass is exposed, light will be produced when electricity is communicated from the machine. Many of our readers may, perhaps, find some difficulty in cutting out these figures or words, and a few practical remarks on the subject, may not be uninteresting.

Let A B C D, fig. 77, be a glass plate, and upon it a piece of tin foil is to be so fixed as to produce a luminous repre-

sentation of the letter L. Cover the glass to within an inch or two of the edge with tin-foil, fastening it with gum or paste. When the gum has set, and before it is dry, cut the tin-foil into slips, having an open space between every slip of foil, taking especial care to rub down the edges with the thumb nail, as every alternate piece is taken away. The lowest slip is made to terminate in a larger piece of foil *p* at the bottom of the plate, and the upper one in the piece *o*. When this has been done, connect each alternate end of the slips in such a manner, that when made to conduct a charge of electricity, the fluid may have a continuous passage through it. Then mark upon the prepared plate the figure or word to be represented, and in all those places where light is required, cut away a small portion of the tin foil. The width of each mark need not be greater than that produced by the pressure of a penknife. Let us suppose the letter L represented in the figure, to be formed in this manner, and the plate to be perfectly dried. Bring the tin-foil at *o* near to the conductor of the machine, so as to receive the sparks thrown off, and let the lower part *p* be connected with the ground. The electricity has a continuous passage except in those parts where the foil has been removed, and these being all illuminated at the same moment present the appearance of a letter of fire. Any,

Fig. 77.



word may be cut out, and with a little management the experiment will be successful. It will be found of advantage to cover the plate with a varnish when finished, for it prevents the foil from being rubbed, and also causes a less deposition of moisture upon the surface, which, when it happens, is sure to prevent the success of the experiment.

A very pretty experiment may be made by placing small pieces of tin-foil in a spiral form round a glass tube. Brass knobs are usually fixed at the end of the tube, and the foil is placed inside to prevent injury by rubbing. A number of these tubes are sometimes fixed together in such a position that the same spark may pass through them all, and the appearance is then very beautiful.

When a charge is passed through a metal chain it is illuminated for the same reason. Take a tolerably large iron or brass chain, and suspend it so as to form festoons. Connect one end of it with an arm of the discharging rod and the other with the outside coating of a Leyden jar. When the jar is charged, touch with the discharging rod the knob that is connected with the interior coating, and a perfect circuit is formed. The electricity rushes through the chain which now forms a connexion between the exterior and interior coatings, and flashes of light will be observed between the links, which are separated from each other by a thin layer of atmospheric air, a non-conducting substance.

Take two pieces of brass chain; and, placing them upon a table, connect an end of one piece with the exterior coating of a jar, and an end of the other with the discharging rod,

in the manner already described. Then bring the other ends near to each other, but not to touch, and on them place a richly cut glass vessel containing water. When the jar is discharged, a spark will be produced between the wires, and the light being reflected from the under surface of the water, a splendid illumination will be observed.

If a charge of electricity be passed through an egg, an orange, or even through the thumb of the experimenter, it will be illuminated. The experiment with the egg is a pretty one, and may be easily made. In a wine glass place a piece of brass chain, sufficiently long to have one end connected with the exterior coating of the jar. Let the egg rest upon the other end in the glass. The charge will pass when the outer coating is connected by a discharging rod with the other end of the egg, which will appear during the passage of the electricity as though it were heated to redness, or filled with a luminous red fluid.

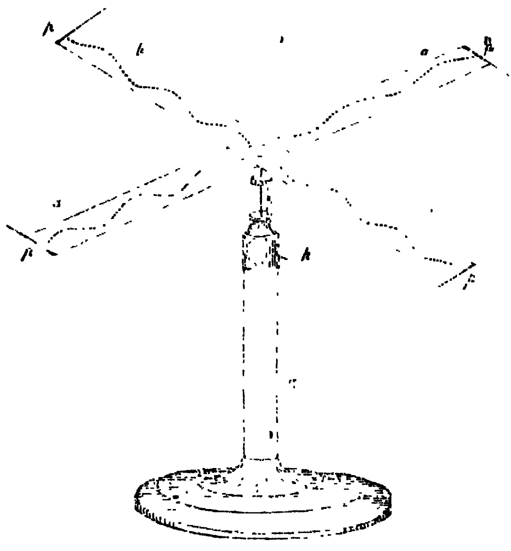
Many other experiments of the same kind will be suggested by the ingenuity of the experimenter, and others, equally curious and interesting, may be found in the published works of electricians.

The author would suggest another manner in which the luminous effects of ordinary electricity may be exhibited, and at the same time accompanied by motion.

Fig. 78. *g* is a glass rod fixed in a wooden stand, and terminating at the other extremity in a brass cap and point, on which is accurately balanced two thin strips of glass *a a*, *b b*. Upon the glass tin-foil is placed, and cut in some device as already explained. At the ends of each strip of glass, points

p p are attached. The instrument is connected with the electrical machine by a chain, which is attached at one end to the hook *h*, and at the other to the prime conductor. Immediately the electricity begins to circulate, the strips of glass will be illuminated, and by the action of the points be set in motion.

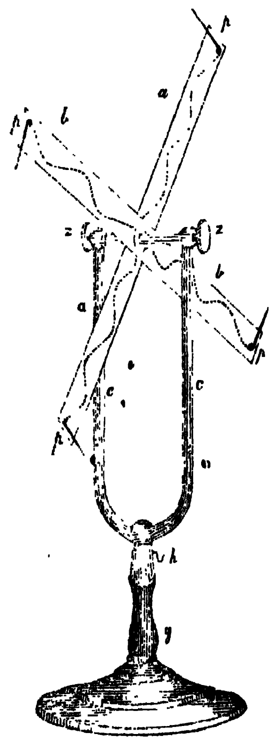
Fig. 78.



Another instrument of the same kind has been described to us as the invention of Charles Barker, Esq., of Gosport, and of it we are bound in fairness to give a description. The instrument is represented in fig. 79, *c c* is a brass rod in the form of a syphon, *z z* is a horizontal piece between

the uprights on which the glass plates, *a a*, *b b*, revolve. The plates are covered with tin-foil as in the former apparatus, and terminate in points *p p*. *g* is a glass column insulating the apparatus, and *h* is a hook inserted in a brass cap, by which the instrument is connected with the conductor of the machine. Light and motion are produced as in the former experiment.

Fig. 79.



In the Annals of Electricity [1], Mr. Sturgeon has described another very interesting instrument for the exhibition of the luminous effects of ordinary electricity; and we have frequently seen in the possession of gentlemen who devote their leisure to scientific pursuits, other arrangements, to which we might refer if our space would permit.

Many theories have been proposed to account for the origin of electrical light. Dr. Wollaston was one of the first who examined the spectrum produced by the electric spark when refracted by a glass prism. M. Fraunhofer performed similar experiments with more particularity. To obtain a continuous train of electrical light he connected two conducting substances by a fine thread of glass, so that when they completed the electrical circuit, a brilliant line of light was produced. To compare the electrical light with that of lamps and the sun, he observed the lines of its spectrum, and discovered they were in every respect different from those obtained in other spectra. These experiments were tested by Sir David Brewster, whose observations will be found in the Edinburgh Philosophical Transactions.

It was generally supposed by the early electricians that the electrical light was, to use M. Biot's expression, "a modification of electricity itself, which had the faculty of becoming light at a certain degree of accumulation." This eminent philosopher objected to the commonly received opinion, and accounts for the phenomenon on the supposition that the electricity acts in the same way as the ordinary pro-

[1] Annals of Electricity, vol. i. p. 114.

cesses of condensation, or in other words that the production of electrical light is "the effect of the compression produced on the air by the explosion of electricity." "The intensity of electrical light," he says, "depends always on the ratio which exists between the quantity of electricity transmitted, and the resistance of the medium." Many objections, however, may be made to this theory, but it is only necessary to state that in the most perfect vacuum we can obtain by artificial means, light is not only produced, but in much greater abundance than in an atmosphere of usual density.

In the year 1822 Sir Humphrey Davy published in the Philosophical Transactions [1] his opinions on this subject; but we shall only direct the attention of the reader to the experiments of Dr. Fusinieri, the results of which were published in 1825, in the journal of Pavia. This philosopher has attempted to prove, that the electricity passing from any metallic conductor, contains that metal in a state of fusion. Thus for instance;—he says, that sparks passing from a globe of silver, consist of incandescent molecules of that metal, and that they may even traverse a plate of copper, some of them being detained by the intervening substance, and others, following the electrical current, may be deposited in the substance to which the electricity is carried. It will be evident, therefore, that he considers electrical light as a flame consisting of minute material particles in a state of incandescence. The author of the paper on electricity in the

[1] Phil. Trans. 1822, vol. xii. p. 72.

Encyclopædia Britannica, draws the following conclusions from Dr. Fusinieri's papers :—

1. "The electric spark is not formed by a pure fluid, or by any imponderable fluid.

2. "The heat and light of the spark proceed from the ignition, and combustion of particles of ponderable matter.

3. "The presence of air produces on the spark two distinct effects, the one to hinder its free expansion in space, the other, by supplying oxygen, to promote the combustion of the exterior molecules of the group, while the centre molecules are luminous, from ignition and fusion alone.

4. "In gases without oxygen, the material molecules which compose the spark ought to be simply in a state of incandescence and fusion without any combustion of the interior particles.

5. "In gases deprived of oxygen, as well as in a vacuum, the molecules which compose the spark, ought to be incandescent; that is, in a state which fits them to emit light and heat, a phenomenon of the same kind as those inflammations which chemical experiments prove to take place, even without the aid of oxygen, in so great a number of other combinations, or even without there being any new combinations, by the sole effect of division of parts."

Dr. Fusinieri has followed out his theory, and attempts to explain upon its principles those meteorological phenomena universally allowed to be produced by atmospherical electricity. It is, however, impossible for us to dwell more at large upon this interesting branch of philosophi-

cal enquiry: we can only refer the reader to the original memoir[1].

HEAT FROM ELECTRICITY.

When a powerful charge of electricity is made to pass through a good conductor of dimensions too small to give it a ready passage, the temperature will be raised. When thin pendulum wires are made the means of transmitting the electricity from a large battery, they are generally fused. Mr. Brook, Keinmayer, Van Marum, Cuthbertson, Singer, and other electricians, have made experiments for the purpose of determining the laws by which this heating power of electricity is governed. "From numerous experiments," says Singer, "it has been concluded by Mr. Brook, and Mr. Cuthbertson, that the action of electricity on wires, increases in the ratio of the square of the increased power; since two jars, charged to any given degree, will melt four times the length of wire that is fused by one jar; and this will be again quadrupled by doubling the height of the charge. But Van Marum contends that the length of wire fused was in direct proportion to the extent of coated surface.

If a piece of gold leaf be placed between two plates of ivory, and a charge be sent through it, fusion will attend the transmission of the electricity. The experiment is now frequently so made, as to form a device upon a piece of satin.

[1] Ann. delle Scienze del Piegn. Lomb. Viento, 1831.

An open pattern is cut, and on one side of it a gold leaf is placed, and on the other a slip of white satin. When the metal is made the conductor of a current of electricity, it is fused, and the figure of the pattern, whatever it may be, is left stained on the satin.

CHEMICAL EFFECTS.

Common electricity has been long known to produce, when properly applied, some chemical effects upon the bodies through which it is made to pass. Great care is required to distinguish the origin of those effects, which are commonly called chemical. When a charge of accumulated electricity is passed through a gold leaf, the metal will combine with the oxygen of the atmosphere, and an oxide of gold will be formed. This is a chemical effect, but it cannot be considered as resulting from the chemical action of the electricity. An intense heat is produced during the passage of the fluid, and it is to that agent the effect must be attributed. An attention to this suggestion is of the greatest importance, or we may be induced to attribute to the chemical influence of electricity, that which results from its mechanical force, and the intense heat occasioned by its passage through inferior conductors, or perfect ones of small dimensions.

The heating effects of electricity are due in a great measure to the mechanical force it exerts upon the bodies whose temperature is raised. Place a sheet of gold or silver leaf

between two plates of window glass, and allowing a small portion of the metal to hang from between the edges of the glass, pass a shock through it, and the glass will be stained with the oxide of the metal. The chances are that in performing this experiment, the glass will be shattered to pieces, which must arise from the expansive force of the confined air, or the concussion received by the particles of the glass during the passage of the electricity.

The same effect is observed when a charge is passed through thick card-board or resin. The latter is best suited for our purpose :—take a thin plate of resin, and placing it against the outside coating of a Leyden jar, let one arm of the discharging rod be brought against it, and the other to the knob of the jar. The circuit is formed by the rod, and the electricity in passing from one surface to the other, has to contend with this non-conducting medium, and breaks it in pieces.

The wires by which a battery is to be discharged, may be separated by a strong glass plate. When the discharge is made, the surface of the glass will have a mark on it, showing the path taken by the electricity. If a thin glass be used, or if weights be placed on that part over which the electricity is to pass, the probability is that it will be broken to pieces, and if the intensity be great, it will be almost reduced to powder.

From these remarks it will be evident that many of the effects produced by the transit of electricity are altogether due to the mechanical or calorific agency of the fluid.

Dr. Priestley appears to have been the first to examine the action of electricity upon the gases. Among other experi-

ments he passed a series of sparks through a tube containing carburetted hydrogen gas, which caused a deposition of carbon. During the course of his inquiries he was induced to try the effect of common electricity upon water coloured with vegetable blue. In making this experiment he used a tube about four inches long, and one-tenth of an inch in diameter. To one end of the tube a piece of wire was fastened, having a ball attached, and the opposite end was immersed in a vessel containing the same fluid as that with which it was filled. When sparks had been passed through the wire and liquid for a few minutes, the upper part of the fluid began to have a reddish tinge. To determine the origin of this change of colour, Dr. Priestley caused so great an expansion of the enclosed air as to expel the liquid, and then introduced a fresh quantity. He afterwards exposed the fluid again to the same operation, but the electricity produced no sensible effect, so that there could be no doubt of the decomposition of the air, and the production of some acid compound. The result was the same with different wires. Nitrous acid was in fact formed by the decomposition of the enclosed air, as was most satisfactorily proved afterwards by a course of very ingenious experiments performed by Mr. Cavendish.

The decomposition of water was effected by Paets, Van Trootwyck, and Dieman, three Dutch chemists. "Being employed with Mr. Cuthbertson in an investigation of the effects of electric shocks on different substances, they had the curiosity to observe its effects on water also. For this purpose they filled a tube of one-eighth of an inch

in diameter, and a foot in length, with distilled water. One extremity of the tube was hermetically sealed, and a gold wire was closed in it, which projected an inch and a half within the tube. The other extremity of the tube was immersed in a small glass vessel full of distilled water, and another wire passed through this aperture, and went up into the tube, so as to be five-eighths of an inch distant from the first mentioned wire. In order to transmit the electric shock, so that it should pass through the water contained in the tube, between the extremities of the two wires, the closed end of the tube was placed against a copper ball, standing insulated at some distance from the prime conductor of the machine; and a communication was made from the extremity of the wire which stood in the vessel full of water, to the outside of a Leyden jar, having one square foot of coated surface, and whose knob communicated with the prime conductor. The electrical machine employed was a very powerful double plate one, on the Teylerian construction, causing the jar described to discharge itself twenty-five times in fifteen revolutions. By a series of shocks with this apparatus, decomposition was effected, and the upper part of the tube was speedily filled with gas. As soon, however, as the electrical discharge passed through any portion of this gas, a re-union instantly took place, water was formed, and there remained only a small quantity of air, which did not entirely disappear; and upon repeated trials it was found that a fresh discharge passed through this residuum would produce further combination, and thus the volume of gas remaining, though never entirely re-combined, became only one-

eightieth of that volume, originally produced by the decomposition."

Dr. Wollaston, a philosopher remarkable for the extreme neatness and minuteness of his experiments, attempted in the year 1801 to decompose water by sparks instead of shocks, and succeeded. In every previous instance the result had been obtained, by using powerful charges: "but when I considered," he says, "that the decomposition must depend upon duly proportioning the strength of the charge of electricity to the quantity of water, and that the quantity exposed to its action at the surface of communication, depends on the extent of that surface; I hoped that, by reducing the surface of communication, the decomposition of water might be effected by smaller machines, and with less powerful excitation than have hitherto been used for this purpose." In this he succeeded fully; but an objection has been made to the supposition of a chemical agency. His apparatus was so minute, that the result has been supposed by some philosophers to arise from a mechanical influence upon the particles of water. Dr. Wollaston was a man of extraordinary philosophical powers, but he frequently put himself to great inconvenience to perform his experiments on so small a scale, that a lens should be required to observe the result. He was a man who seemed to delight in operations made in almost capillary tubes, and prided himself in a voltaic battery formed of thimbles.

Of all the experiments yet made with a view to determine the chemical effects of ordinary electricity, those recently performed by Professor Faraday are by far the most impor-

tant. He succeeded in decomposing water so as to obtain the two elements separately, and thus removed the objections before attached to the supposition of the chemical influence of the agent. He has likewise put us into possession of a means by which our observations on other substances may be conducted with greater facility. It must, however, be evident that the chemical effects produced by the electricity of the machine are comparatively unimportant, and we may refer the reader to Dr. Faraday's description of his own experiments in the Philosophical Transactions.

MAGNETIC EFFECTS OF ELECTRICITY.

Those who studied electricity as a science even when in a crude and imperfect state, were fully convinced that some intimate connexion existed between those two principles we call electricity and magnetism. It had often been noticed that lightning destroyed the polarity of needles, and produced magnetism in ferruginous substances not before possessed of the property. Ships at sea, when struck with lightning, often have had the polarity of their needles destroyed or reversed, and cases have been known in which the ship has, after a storm, been steered in a wrong direction, till the error was detected by an astronomical observation. In the Philosophical Transactions many papers will be found in which the communication of magnetism to a piece of iron is said to have been produced by the passage of lightning through them. In the same work Mr. Robins has stated, that the needle of a compass is slightly disturbed even by

rubbing the outside of the glass. This also is an electrical phenomenon, for the fluid is set free by friction, and until it is dissipated, acts upon the magnetic needle with sufficient power to derange its influence, and therefore to neutralize in some degree the terrestrial action.

When Franklin commenced his investigation of the identity of ordinary and atmospheric electricity, his attention was drawn to the magnetic effects produced by lightning, and he endeavoured to discover whether the same could be produced by the electricity of the machine. After charging four large jars he passed their contents through a sewing needle, and found that it acquired the magnetic property. When the needle was placed in the plane of the magnetic meridian, that end which pointed to the north became the north pole, whether the electricity was passed from north to south, or south to north. When the needle pointed east and west, that end became the north pole at which the electricity entered. A piece of steel wire placed perpendicular to the plane of the horizon, was magnetised in the same manner; that end nearest to the earth being always the north pole. These experiments may be easily verified by the reader; a much less extensive apparatus than that used by Franklin, being sufficient for the purpose. They will, however, be best performed by placing the needle in a helix formed of copper wire.

In the same manner magnetism may be deranged or destroyed, for if a strong charge be passed through a small magnet, it will either lose its power or have its poles reversed.

A magnetic needle may also be deflected from its position by ordinary electricity, a phenomenon frequently produced by the Aurora-Borealis. Many electricians have denied the possibility of producing this effect with the machine; but Dr. Faraday succeeded by using batteries of great power. The apparatus was so arranged that, while the needle was completing one vibration, the battery could be charged, and when the needle returned to its first direction, the discharge was again made. By repeating this for a few times the vibrations extended to above 40° on each side of the line of quiescence. It is worthy of remark, that although the same results were obtained, whatever conductor was used, imperfect conductors succeeded best, having the power of converting the strong charge into a somewhat continuous current. There is, however, no necessity for this large and expensive apparatus. If a needle be delicately suspended, and a stream of electricity issuing from a point be poured on it, the needle will be instantly deflected. The experimenter may at first find some difficulty in obtaining the desired effect, but a few trials will enable him to place the needle at once in the situation where the effect is most powerful.

THE PHYSIOLOGICAL EFFECTS OF ELECTRICITY.

The sensation produced by receiving the spark, and the more powerful one experienced when any portion of the body forms a part of the circuit through which a charge from the two sides of a coated jar returns to the state of electrical

equilibrium, must be familiar to every one. From the effects produced on inanimate matter, we might expect that this mysterious fluid would have some singular influence upon the vital system. Such is the fact, for in addition to its chemical and mechanical effects upon bodies, it exercises a mysterious influence upon the living powers, and more especially upon the nervous system.

We are not sufficiently acquainted with the nature of the electric agent, to give a satisfactory reason for its singularly violent action on those bodies through which it passes. The involuntary muscular motion may be produced by an influence on the nervous system, or by the passage of a subtle fluid through the substance of our bodies, or by the sudden decomposition of their natural electricity.

The reason why the shock is more severely felt at the joints than any other parts of the body, may probably be traced to the impediment it suffers in passing from one surface of the bone to another, at the parts where the continuity of substance is interrupted by the joints. If a shock be directed through a muscle, its chief effect is the production of a convulsive and involuntary action. If a paralyzed limb be placed in the electric circuit, this action is occasioned, though the nerves are incapable of conveying the impression which produces sensation.

But it is upon the nervous system that electricity produces the greatest effect. A strong shock passed through the body of an eel, instantaneously kills it, but when a part of its body is included in the circuit, only that part suffers the destruction of irritability. Small animals, such as mice and

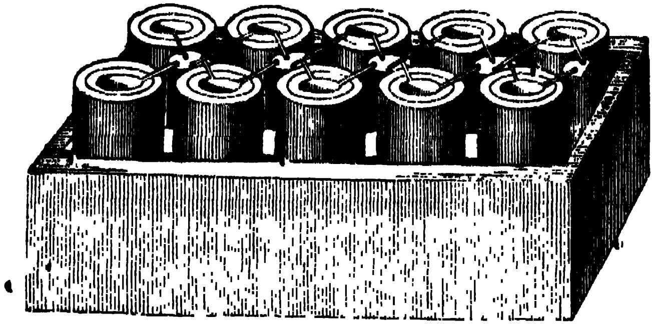
sparrows, are killed by a shock from thirty square inches of coated surface. If a charge be sent through the head of a bird, it generally injures or destroys the optic nerve.

Mr. Singer discharged through his own head a strong shock, which occasioned the sensation of a violent blow, and was followed by a transient loss of memory, and indistinctness of vision. If a person who is standing receive a charge through the spine, he loses his power over the muscles to such a degree, that he either drops on his knees, or falls prostrate on the ground. If the charge were very powerful, it would produce immediate death, in consequence, probably, of the sudden exhaustion of the whole energy of the nervous system.

These are effects occasioned by the passage of an electric shock through the body under particular conditions; but the shock produced by the discharge of the Leyden jar through the arms, only causes an agitation of the muscles, which is more or less powerful, in proportion to the intensity of the charge. But it is curious to read the ridiculous and exaggerated statements made by the philosophers who first received the shock. These accounts naturally excited the wonder of all classes, and every one was anxious to see the strange effects; which induced a number of uneducated men to wander about through our own and other countries, imposing upon the public, and, as it ultimately proved, bringing the science itself into disgrace.

CONCLUDING REMARKS

The curious and interesting phenomena exhibited by lecturers on electricity have made the study popular, and there is, now, no branch of physical science so generally known. During the last twenty years the attention of philosophers has been directed to new investigations, and but little has been done, comparatively speaking, towards the full development of the science of ordinary electricity. It is a singular fact, that we have not in the English language a complete treatise on either branch of electricity;—the best papers on the subject, are those published in the Encyclopædia Britannica and Metropolitana. Ordinary electricity is perhaps the only electrical science in a state permitting such a combination of facts, as would be required in a work professing to examine and explain all that has been done by observers, and to decide between conflicting statements. The few preceding pages are intended to initiate the reader, but it is our intention at no very distant period to present the public with as complete an exposition of the science as our investigations shall permit.



VOLTAIC BATTERY.

CHAPTER VIII.

VOLTAIC ELECTRICITY.

No branch of science has, during the last twenty years, engaged more of the attention of philosophers generally, than that which we are now about to explain. The task we have undertaken is by no means an easy one, so great is the number, and so complicated the nature of the facts developed by the researches of modern philosophers. It would be difficult to prepare a full account of the science, but it is much more so to give one that must be brought within the limits of a few pages. To select from one of the most extensive and difficult branches of science those principles,

most likely to assist him who is commencing the study, and to arrange these in an order that will lead him forward to a practical acquaintance, is attended with more difficulty than he who has not made the attempt, would be willing to believe. After making every exertion to facilitate the progress of the student, we must conduct him over a difficult and somewhat tedious road, but it will lead to a magnificent and fertile country, the beauty of which will be the better appreciated from having reached it with some fatigue. There is, however, much to support the energy and excite the curiosity, in the least interesting part of the journey.

HISTORY OF VOLTAIC ELECTRICITY TILL THE INVENTION OF THE PILE BY VOLTA[1].

It is always an interesting, and by no means an unprofitable task, to compare the amount of our knowledge with that possessed by those who have been engaged in similar pursuits at earlier periods. The advantages to be derived from this comparison are obvious; but in spite of them we are apt to pass by with neglect, and even with contempt, the efforts made by men whose names and exertions should be held in reverence by those who are building a temple to their own fame, on the foundations they so securely laid. In ages that are past, time has obliterated the recollection of facts and principles essential to the intellectual advancement, and well

[1] This paper was read before the Electrical Society.

being of society; and many who ought to occupy the higher seats in the temple of Fame, are altogether unknown. But the power which time has exercised over the records of men and nations, is now combated by the art of printing; and the honour of illustrious men is more securely preserved than if engraven on rocks of granite or tablets of brass. The advantage to be gained by a review of the labours of those who preceded us is ours; for if we neglect to give them the honour that is their due, their fame cannot be sullied, as posterity will not fail to estimate their labours by a comparison with our own.

The history of galvanism, or, as the science is now with propriety called, Voltaic electricity, is as interesting to the mental, as to the experimental philosopher; for although it is impossible to estimate the intensity of mental energy expended on it, we may form some opinion of the capacities and talents of those who have been engaged in raising the imposing but still irregular combination of facts which compose it. We have sometimes attempted to imagine ourselves surrounded by the men to whom the very existence of the structure may be traced; Galvani, Volta, Welis, Davy, Wollaston, and a multitude of others. What a concourse of gigantic minds, and yet how different in their habits of thinking, and in the power of particular faculties—all the varieties between the extreme of microscopic examination and a universal grasp of facts, fit to combine the divided fragments into the fashion of a goodly edifice. It is true that many of these philosophers entertained very contrary opinions; but as stately forest trees driven by the wind lash

each other, bending backwards and forwards, and sheltering the tender shrubs within the reach of their branches, so *they* have nourished and protected the tender shoot which, growing to a strong and wide-spreading tree, has shot its branches downwards, each in its turn becoming an independent, and yet a subsidiary source of fruit.

The experiment which first led to the establishment of the science of Voltaic electricity was made by accident in the year 1791, but was afterwards investigated by Galvani, whose name was for a long time attached to the science itself. This philosopher was, it appears, making experiments to prove a theory he had adopted,—that electricity is the cause of muscular motion.

Some dissected frogs were on the table near to an electrical machine, which was in action. Galvani happened to touch at this time a certain nerve of one of the frogs, and observed an immediate contraction of its limbs. This singular result seemed so favourable to his theory, that he immediately commenced an investigation of the phenomena. The effect was at first attributed entirely to the common electricity, but finding that the contractions were also produced when the animal was merely placed on an iron plate, and touched with another metal, especially silver, he perceived there must be some other cause for the phenomenon. After performing numerous experiments, he published the results of his inquiries [1], which he explains by supposing

[1] Aloysii Galvani de Viribus Electricitatis in motu musculari Commentarius, Bononiæ, 1791.

that electricity is secreted by the brain, and has a permanent residence in the muscles,—that the inner parts of the muscles are in a positive, and the outer in a negative state, resembling in every respect a charged Leyden jar, and that the nerves act the parts of conductors, discharging the accumulated electricity of the inner surface of the muscle in the same manner as a discharging rod connects the exterior and interior coating of a jar.

The contraction is therefore supposed to be produced by the exciting influence of the electricity; and in proof of this theory, he states, that it is not necessary to use a metallic or other substance, but that parts from the body of the animal are sufficient for the production of all the effects, as he found by applying the lumbar nerves to the crural muscles. Still he acknowledges that the effects are more evident when a metallic arc is employed, and chiefly so when the parts are united by two metals.

In these experiments we have the first glimmering of a science, which, in less than half a century, was destined to throw a searching light into the very recesses of Nature's laboratory. It is curious to observe how nearly Galvani was led in his investigations to the truth; but with a mind already strongly possessed in favour of a particular theory, and considering every experiment in reference to that theory, it is not singular that he should have passed by the most important fact developed in his experiments, that the contractions were greatest when the muscles were connected by two dissimilar metals.

The experiments of Galvani were admirably adapted to

encourage, if not to satisfy, the speculative physiological opinions of his day. They instantly, therefore, excited the attention of some of the most celebrated philosophers of Europe, who repeated them in various ways, and either rejected the investigations as unworthy of regard, or so modified Galvani's theory as to suit it to their own particular views. Some of the speculations indulged in were more characterised by their boldness than their wisdom; while, on the other hand, some were dictated by an uninquiring scepticism. Professor Pfaff denied the existence of electricity in the experiment, and showed that Galvani's supposition of a negative and positive state of the muscles, was perfectly unsupported by experiment. But although he perceived the want of evidence in Galvani's theory, he did not hesitate to make a more violent assumption; that, the agent developed in the experiment was analogous to, if it were not, the principle of life, and yet allowed that it may be conducted by metals. Spallanzani admitted that electricity might be the cause of the contraction, but imagined it to be obtained from external agents, and not from the muscles of the animal.

Of Dr. Valli's experiments and opinions we must speak with more particularity, as he has left us a full account of the results he obtained [1]. This gentleman admitted that the contractions were produced by electricity, which he considered identical with the nervous fluid. He rejected, however, that part of Galvani's theory which attributes a different

[1] Experiments on Animal Electricity with their application to Physiology. London, 1793.

electric state to the two surfaces of a muscle. The evidence of the identity of the nervous and electric fluids, may, he thought, be established, because the same substances conduct both, and those which refuse to conduct the one, equally resist the progress of the other. It is strange, however, that one, who was no doubt a close observer of facts, should have so singularly failed in the establishment of his theory. He first assumes that the nervous and electrical fluids are the same, and consequently that the agent producing the contractions may be called by either one name or the other; and then he tells us that their identity is proved by both being conducted or non-conducted by the same substances, or in other words the substances which transmit the ordinary electricity are capable of exciting the contractions. Under these circumstances it is not surprising that he should be able to prove a perfect identity, and to show that attraction is a property of the nervous fluid as well as of electricity.

But although Dr. Valli's theory entitles him to but little regard; some of his experiments were useful in aiding the progress of the science. He observed that the contractions were much less powerful when excited by common electricity from glass or resin. Two metals, he says, are necessary to produce the contractions, and when one has been found sufficient, it cannot have been homogeneous, or in other words there must have been a difference of quality, which he supposed sufficient; having obtained the effects from two pieces of lead. He found by experiment, that many animals beside the frog exhibited the same phenomena from the con-

tact of metals; that they could not be produced in animals killed by starvation or mineral poisons; and that those which had been drowned might occasionally be resuscitated.

Dr. Munro of Edinburgh opposed these opinions entirely, for he could neither believe the agent to be electricity, or to be identical with the nervous fluid. What it might be he does not state, but satisfies himself with the belief that it has a powerful exciting influence on the nervous fluid, to which alone he attributes the contractions.

VOLTA'S THEORY.

From what has been already said it will appear, that all the philosophers of whom we have hitherto spoken, either considered the contractions to be produced by some unknown agent, or by the influence of a species of animal electricity, a fluid belonging to the structure of the body, in which the excitement was produced. At the commencement of the year 1793, two letters written by Professor Volta of Pavia, and addressed to Mr. Cavallo, were read before the Royal Society. In these communications he expresses his entire dissent from all the theories that had been proposed to account for the physiological effects of which we have been speaking. He admitted that the agent was electricity, but could not allow it to be obtained from the animal body, much less from an opposite state of electricity in the two surfaces of a muscle. His experiments proved that

contractions could be produced when the circuit was formed between two parts of a nerve or two muscles, or between different parts of the same muscle. Reasoning on these results, Volta concludes that the contractions are produced by a disturbance rather than a restoration of electric equilibrium. The mere contact of the metals, he states, does disturb their electricities, and the frog being in the circuit of the fluid, is in fact nothing more than a delicate electrometer. Having discovered that this electricity had so great an influence on dead animals, he wished to ascertain its effects on the living, and taking a plate of silver and zinc applied them severally to the upper and lower surfaces of his tongue. But instead of contraction, as he had imagined, a peculiar taste was excited; a fact for which he could account when he remembered that the nerves at the tip of the tongue were for sensation. Contraction however was produced when the nerves at the root of a tongue recently removed from a sheep, were acted on by the electricity of the plates.

Looking at the science of Galvanism in its present state, with the mind occupied by all the accumulated evidence of modern research, it is almost impossible to form an estimate of the close perception of facts and the ingenuity of Volta, in thus rejecting the theories of his contemporaries, and introducing one which at first sight seems so utterly improbable. But it will be observed, that Volta here considers only one class of phenomena, those produced when two metals form the contact. This was noticed by all those whose attention was directed to his theory, and he found but few who were willing to adopt his opinions.

Passing over a multitude of writers who commented on the discoveries of Volta, and introduced a few modifications of the experiments already described, we may allude to his second paper, communicated in two letters to Professor Gren. He commences with a description of an experiment which has been very frequently made, and has probably been seen, by all our readers. Take a tin basin and nearly fill it with lime water or a strong ley; and after immersing the hands in water place them on the basin, and apply the tongue to the fluid; an acid taste will be perceptible, although the fluid itself is alkaline. "The stream of the electric fluid," he says, "passes from the tin to the alkaline liquor, and from thence to the tongue again."

Volta divides the conductors of electricity into two classes, those which are dry, such as metals and charcoal, and those which are fluid; and the contact of a substance belonging to one class with one belonging to the other, is supposed to agitate, disturb, or give an impulse to the electric fluid.

"Do not ask," says Volta, "in what manner; it is enough that it is a principle, and a general principle. This impulse, whether produced by attraction or any other force, is different or unlike, both in regard to the different metals and to the different moist conductors; so that the direction, or at least the power, with which the electric fluid is impelled or excited, is different when the conductor A is applied to the conductor B, and to another C. In a perfect circle of conductors, where either one of the second class, moist conductors, is placed between two different from each other, of the first class, dry conductors, or contrary wise, one of the

first class is placed between two of the second class different from each other, an electric stream is occasioned by the predominating force, either to the right or to the left;—a circulation of this fluid which ceases only when the circle is broken, and which is renewed when the circle is again rendered complete."

Volta was now able to explain why contractions were produced upon an animal body by a single metal. To follow this great philosopher through all the experiments and reasonings by which he was led to those opinions which had a vast influence in establishing the science of galvanism is quite impossible, but we would recommend a perusal of the original article, which may be found in the third and fourth volumes of Tilloch's Magazine.

Volta first states that no stream of electricity can be obtained by the use of two conductors, how numerous soever the alternations may be, and consequently no convulsive animal movement ought to be expected. Three elements are required, and they may be either two liquids and one solid, or two solids and one liquid. A drop of water, a moistened sponge, or a thin stratum of soapy or other viscous matter when introduced between two metals is, he says, sufficient for the production of electric currents. "This surprising experiment, I generally make in such a manner that, instead of the piece of metal, I employ a cup or spoon filled with water, and then cause a person who holds a perfectly dry and pure stick of tin to touch with that stick the perfectly dry sides of the spoon, or cup, at one time, and the water contained in it at another. It is wonderful to observe that

as by the latter method the violent agitation of the frog never ceases, the first method does not produce the least agitation, unless by accident there be a small drop of water or a thin stratum of moisture at the place of contact."

Speaking of that class of Voltaic arrangements in which two liquids and one solid are used, Volta says, "That method of combination in which a metal placed between two different moist conductors, for example, between water on one side and a saponaceous or saline fluid on the other, I discovered in the autumn of 1794, and though since that period I have repeated the much varied experiments of different persons, and though I wrote to several correspondents respecting it, that light has not been thrown on this new phenomenon which it seems to deserve.

"The singular circumstance, before-mentioned, of an acid taste being produced when the tongue is brought into contact with an alkaline liquid, belongs, as you may perceive, to this second method of exciting the electric fluid, and putting it in circulation, and shows that this current is no less strong and active than that excited by the first method, namely by employing two well-chosen metals, such as lead and copper, iron and silver, zinc and tin. I must here observe, that though with tin alone, placed between water and an alkaline liquor, you may obtain nearly the same effect as that produced by two of the most different metals, such as silver and zinc, combined with any conductor of the second class, it is easy to obtain the same even in a higher degree with iron or silver alone, when the iron is introduced between water on the one side, and nitrous acid on the other, or when the

silver is applied between water and a solution of sulphate of potash."

Having thus ascertained the principle of Voltaic arrangements, and the varieties of which they are capable, Volta goes on to investigate the relations they bear to each other. Into this enquiry, however, we cannot at present enter; sufficient has been said to prove our obligations to Volta, to whom Sir Humphry Davy was much indebted in the similar investigations he afterwards instituted.

In March of the year 1800, Professor Volta again addressed the Royal Society, in a letter to Sir Joseph Banks, who was then the president. The same year it was read and published in its original form in the Transactions. Of all Volta's papers this is without doubt the most important, and if we were to say more important than any paper that has been since written, we should not give it an undue prominence. It was here that he laid the broad and enduring foundation to his own imperishable honour, and the science which bears his name. It was here he first described that instrument which, in his own words, contains an inexhaustible charge, a perpetual action or impulse on the electric fluid, and which, whatever modifications it may receive, must ever be called the Voltaic Battery.

It has frequently happened in the annals of science, that the attention of philosophers has been called, by a combination of facts, to a particular investigation, and a great improvement or discovery has been made simultaneously by persons who have had no means of intercourse. At other times claimants have arisen; and because they thought of some-

thing like that which had been discovered, or because they despaired of obtaining honour by any other means, have with shameless impudence placed an unholy hand on the highest honours a man can enjoy—the satisfaction of having first trod, and alone, a secret path in the fruitful and pleasant garden of external nature. Volta, however, enjoyed the exceeding pleasure of knowing that there was no rival for his fame, none with whom he was compelled to divide his laurels.

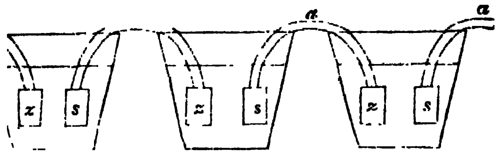
We must come, however, to the paper itself, and endeavour to explain as briefly as possible the several arrangements by which Volta succeeded in developing a current of electricity from the mere contact of conducting substances. In doing this we shall follow as nearly as possible the description he gave of them.

He first provided himself with a few discs of copper or silver, and an equal number of zinc (about an inch in diameter), also pieces of paper, or some other substance capable of retaining moisture, rather smaller than the plates of metal. Having well moistened the pasteboard with salt water, he commenced the arrangement of his plates. Upon a table or stand he first placed a plate of copper, then one of zinc, and then a piece of pasteboard; on this another plate of copper and pasteboard, continuing the alternations as frequently as required, the pasteboard discs being previously well moistened with water, or, as is preferable, acidulated water. This instrument is called Volta's Pile, and from about twenty pairs slight shocks resembling those of a weakly charged battery, or of an exhausted torpedo, were

felt. The intensity of the shock he well knew to depend on the number of alternations; for he observed that although twenty pairs of plates could only affect a finger, or a small portion of the hand, when fifty plates were used both arms felt the force of the shock.

Volta finding the columnar form of his arrangement very inconvenient in some respects, invented another, which though occupying more space had many advantages over the pile. This apparatus was called the *Couronne de Tasses*, or Chain of Cups, and is represented in the following diagram. "I dispose," says Volta, "a row of several basins

Fig. 80.



or cups of any matter whatever, except metal, such as wood, shell, earth, or rather glass; (small tumblers or drinking glasses are the most convenient,) half filled with pure water, or rather salt water or ley: they are made all to communicate by forming them into a sort of chain, by means of so many metallic arcs, one arm of which *s a* or only the extremity of *s* immersed in one of the tumblers, is of copper or brass, or, still better, of copper plated with silver; and the other *z a*, immersed into the next tumbler, is of tin or zinc. I shall here observe that ley and other alkaline liquors are preferable when one of the metals to be immersed is tin; salt water is preferable when it is zinc. The two metals of

which each arc is composed, are soldered together in any part above that immersed in the liquor, and which must touch it with a surface sufficiently large: it is necessary, therefore, that this part should be a plate of an inch square, or very little less; the rest of the arc may be as much narrower as you choose, and even a simple metallic wire. It may also consist of a third metal different from the two immersed in the tumblers, since the action on the electric fluid which results from all the contacts of several metals that immediately succeed each other, or the force with which this fluid is at last impelled, is absolutely the same, or nearly so, as that which it would have received by the immediate contact of the first metal with the last, without any intermediate metals, as I have ascertained by direct experiments.

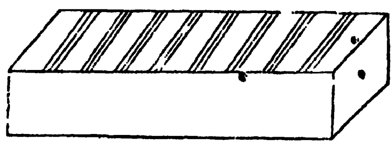
"A series of thirty, forty, or sixty of these tumblers connected with each other in this manner, and ranged either in a straight or curved line, or bent in every manner possible, forms the whole of this new apparatus, which is in substance the same as the columnar one above described; as the essential part, which consists in the immediate communication of the different metals which form each couple, and the mediate communication of one couple with the other, namely by the intervention of a humid conductor, exist in one as well as the other."

PRODUCTION OF VOLTAIC ELECTRICITY.

Having traced the history of Voltaic Electricity to that period when he whose name is given to the science discovered an arrangement by which the fluid can be obtained in large quantities, we must abandon the historical style and adopt the descriptive. Both the arrangements proposed by Volta are exceedingly defective, and have consequently been superseded by others. The pile when it consists of a number of pieces, is very troublesome, not only because it takes a long time to erect it, but also because the liquid in the lower cloths is pressed out, and the action is diminished. Volta was aware of this, and in consequence invented the Couronne de Tasses, which is, however, much less effective, and has been entirely abandoned by modern inquirers.

Mr. Cruickshanks was the inventor of that arrangement long called, by way of distinction, the Voltaic Battery. It consists of copper and zinc plates, cemented into a water-tight trough, fig. 81, of well-seasoned wood, at short distances from each other. A copper plate terminates the

Fig. 81.



series at one end, and a zinc plate at the other, as in the pile. When the instrument is to be put in action, the trough

is filled with water containing a small proportion of sulphuric acid. Those who first used the instrument were accustomed to say, that the liquid should be of such a strength that a stream of gaseous bubbles might rise from a piece of zinc immersed in it.

In using the trough battery, however, the experimenter is subject to much inconvenience, and especially that arising from the very rapid exhaustion of its power. The quantity of acid in each trough is so small, that it is soon saturated with the oxide of zinc, after which there can be no further action. Nor indeed when the instrument is used under the most favourable circumstances, do we ever obtain its full power. In making a course of experiments it is exceedingly annoying to know that the power of the instrument is every moment becoming less and less from the action of the acid on the metal, and the trouble of filling and emptying large troughs, not only interrupts but wastes much time. Another construction has therefore been adopted, and in this the plates are so arranged that they may be removed from the trough when the instrument is not wanted, and its energy be consequently preserved.

It was afterwards discovered that a greater galvanic action may be developed by having the copper plate of a larger size than the zinc, the maximum proportion being about seven to one. Dr. Wollaston on this account proposed that the zinc should be surrounded with copper, as in fig. 84, and it is calculated that a trough constructed in this manner exceeds any other by the whole power, and it is evident that

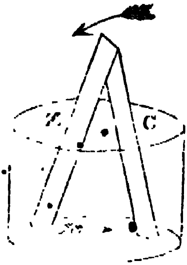
the chemical action must be in this proportion, for both sides of the zinc are acted upon.

We have hitherto spoken of the electrical effects produced by two dissimilar metals and an oxidating fluid, capable of acting on one more than the other, and we have taken as our example zinc, copper, and an acid solution; but a Voltaic arrangement may be formed consisting of one solid and two liquids.

Every galvanic combination must consist of three elements, and one of these must be a solid, the other a fluid; the third may be either a solid or a fluid, and its being the one of the other will place it in a particular class. Of all the solid elements capable of forming galvanic combinations, the metals and charcoal are the most efficacious. Of fluid elements those which produce the greatest chemical action upon the solids are to be preferred, such as the mineral acids, alkaline solutions, sulphurets, and solutions of neutral salts. The energy of the combination will depend upon the chemical action, and electricity can never be excited if there be no chemical energy. Thus silver, gold, and distilled water do not constitute a galvanic circle, because no chemical action is developed, but an addition of a small quantity of nitric acid will render it active in the production of that agent.

For the development of electricity it is necessary that the three elements should form a circle. Thus, if a plate of copper and zinc be in contact at one of their extremities, the other being immersed in a diluted acid, a galvanic circle will be formed. There will here be a current of positive electri-

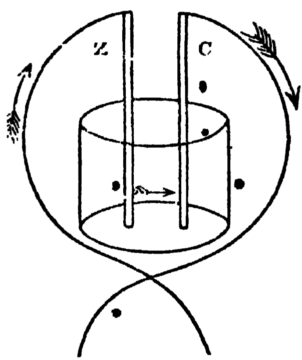
Fig. 82.



city passing from the zinc to the acid; from the acid to the copper, and from the copper to the zinc; as shown by the arrows in fig. 82; and there will also be a current of negative electricity circulating in the opposite direction, from the zinc to the copper, from the copper to the acid, from the acid to the zinc. This effect is produced only so long as the metals are in contact; as soon as they are separated, the current ceases.

A communication may be established between them by a metallic wire, fig. 83, or two wires, one attached to each plate, and we shall still have a Voltaic combination. The

Fig. 83.

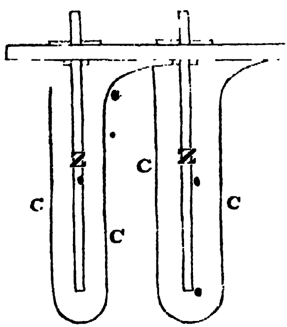


direction of the positive electricity is, in the fluid, from the zinc to the copper, in the wire, from the copper to the zinc,

as shown by the arrows. The negative electricity will of course take the opposite direction. All arrangements consisting of a single ternary combination of elements are called simple circles or batteries, and it is easy to see in this instance which is the positive, and which the negative end. The positive electricity, as we have already shown, issues from the wire attached to the copper, and enters that belonging to the zinc, and therefore the copper must be the positive side, and the other, that is the zinc, must consequently be negative.

When a number of these ternary elements are combined, they form a compound circle: to this class all the piles and batteries of which we have spoken belong. Let fig. 84 represent the section of a compound battery in which the zinc

Fig. 84.



and copper plates Z and C are combined in pairs connected at their upper edges by small slips of metal. Each pair is

immersed in a separate vessel containing diluted acid. The direction of the electric current is the same in the compound as in the simple battery, that is to say, the stream of positive electricity is constantly circulating from the zinc to the copper through the fluid in each vessel; and then from the copper to the zinc of the next vessel, through the metal that connects them, and so on to the end. It is therefore evident that in a compound battery the zinc end will be the positive pole; and it will be equally clear that this variation from the simple battery, the copper being in that instance positive, does not arise from any difference in the directive motion of the electricity, but only from the combination.

Having premised these few observations we may now proceed to consider some of the facts relating to the two classes of voltaic combinations; and first of that which consists of two solids and one fluid. The arrangement we have hitherto taken has been the one commonly employed, copper, zinc, and diluted acid, but a great variety of other substances may be used. Bearing in mind the principle to which we have already alluded, that chemical action must be developed, any substances may be employed.

Lagrave has stated that he formed a galvanic arrangement by alternate layers of muscle and brain with pieces of moistened cloth interposed. Dr. Baconio made a pile of only vegetable substances and obtained electricity sufficiently strong to produce contractions in the muscles of a frog.

It is found when metals and an acid are used, that the power of the combination in the production of electricity will be in proportion to the oxidability of the body, and moreover

that every oxidable metal is positive in relation to every other, which is less oxidable than itself. The following is a table given by Sir Humphry Davy, of the metals in the order of their oxidability,—and every substance is positive when used with either of those below it:—

1 Potassium and its amalgams.	11 Copper.
2 Barium and its amalgams.	12 Silver.
3 Amalgam of Zinc.	13 Palladium.
4 Zinc.	14 Tellurium.
5 Cadmium.	15 Gold.
6 Tin.	16 Charcoal.
7 Iron.	17 Platina.
8 Bismuth.	18 Iridium.
9 Antimony.	19 Rhodium.
10 Lead.	

The greater the distance between the two elements, the greater will be the electrical effects of the voltaic compound they form, thus zinc and iron will form a much weaker arrangement than zinc and copper.

When alkaline substances are used instead of acids, the order of the metals is not precisely the same, and there are some acids which will, when used, change the relative order of the metals; with the hydro-sulphurets, the order is still more confused.

The second class of galvanic circles consists of those which are composed of one solid and two fluid elements. In this arrangement it is necessary to separate the two fluids, which may be done by placing them in two distinct vessels, and causing them to communicate by means of a bent tube,

containing a conducting liquid. Sir Humphry Davy used, in some of his experiments, fibres of moistened asbestos instead of tubes.

Davy, to whom the science of electricity is so much indebted, has divided this class into three kinds of circles.

1. That in which a single metal is so placed as to have its opposite sides acted upon by different liquids, one having a power to oxidize, the other being destitute of any chemical action. Zinc having acid on one side, and water on the other, is a circle of the kind. This arrangement is very feeble, and its effects can scarcely be detected unless one of the most oxidable metals be used. Sir Humphry Davy, states that a pile formed of tin, acid, and water, and consisting of about twenty alternations will decompose water slowly, and give a slight shock. If we compare this class of galvanic arrangement with that before described, in which two metals and an acid are employed, it will be found to differ but in one particular—the introduction of a liquid in the place of a solid; thus, for instance, water takes the place of copper. In both cases this third element has the same office, that of a conductor between the other two. The great weakness of the electricity developed by one system, in comparison with the other, may be traced to the difference in conducting powers, water having the property in a very inferior degree to copper.

Persons are not generally aware that porter and other liquors are better when drunk from a metallic vessel, because a voltaic circuit is formed. In the act of drinking out of a silver cup a ternary compound of the same kind as that

just mentioned is formed. The vessel itself is the solid, the porter or wine is the fluid presented on one side, and the saliva is the fluid on the other side. As soon therefore as the porter comes in contact with the tongue, the voltaic circle is complete, and a stream of electricity is put into motion which seems to affect in some measure the taste.

2. The second kind of voltaic circle consists of a metal which may be acted upon by sulphureted hydrogen, having on one side a solution of some hydro-sulphuret, and on the other water. Copper is the metal most suitable for this purpose, but silver or lead may be used. "There are," says Sir Humphry, "some singular circumstances connected with the violent chemical action of copper on solutions of the hydro-sulphurets. When a piece of copper has been for a minute, in a strong solution of hydro-sulphuret of potassa, on introducing a piece of polished copper, there is often a strong negative charge communicated, which sends a needle through a whole revolution—oscillates, returns, and takes the direction which indicates that the piece first plunged in is negative."

When an egg is eaten with a silver spoon, the metal is discoloured by the sulphur contained in the yolk of the egg, and the combination may be promoted by the electric current, for a voltaic arrangement of the second kind is formed.

3. The third combination of this class consists of a metal acted upon by an acid on one side, an hydro-sulphuret on the other. A pile of twelve or thirteen alternations is sufficient to decompose water. Copper is the metal with which

the greatest effects are produced, and next to this silver or lead.

These are some of the most important facts relative to the formation of voltaic arrangements, which are, as must be perceived, more frequently present, both in nature and experimental researches, than might be anticipated. No three bodies can be in contact, a chemical action existing between two of them, how slight soever it may be, without putting in motion currents of electricity. It cannot be doubted that this frequently happens in the arrangement of the solid materials composing the crust of our globe, and that considerable currents are thus put in circulation. The atmosphere itself in certain conditions may become a member of a vast, natural ternary arrangement, the effects of which cannot very easily be estimated.

Modern philosophers entertain no doubt of the identity of the voltaic and ordinary electricities, an opinion formed from a consideration of the similarity of effects produced by them. But although the fluid is the same in both cases, yet it is in different conditions: when developed by the machine it is in a state of great tension; in the voltaic battery it has little tension, but is set free in large quantities. The intensity of the electricity in the former case, is shown by the divergence of the quadrant electrometer, but in voltaic electricity the effect is different, for when a wire is conducting a large quantity of the same agent, it affords no indication of intensity by affecting the electroscope.

Another common result of ordinary electricity is the attraction of non-electrified, and of dissimilarly electrified sub-

stances. Upon this principle the gold-leaf electrometer is constructed, and we have seen that by bringing a very feebly excited body, into connexion with the cap of the electrometer, the leaves will diverge. But a single pair of voltaic plates however large, and whatever amount of electricity they may develop, cannot produce this effect. With fifty pairs of plates the electroscope is slightly affected.

From these facts it will appear that the intensity of ordinary electricity is very superior to that of the voltaic. But although the tension of voltaic electricity is so inferior, yet it is capable of feebly charging a Leyden jar, and when thus accumulated it may be used for any experiment in the same manner as that collected from the machine. These facts also suggest that the tension of voltaic electricity is increased in proportion to the number of alternations. For the production of all those effects requiring great intensity, a number of plates must be employed; but for the production of calorific effects, surface and not alternation is required.

AMALGAMATED ZINC.

Voltaic batteries have been recently formed of amalgamated zinc, and are found to have many advantages over those of the common construction. Sir Humphry Davy appears to have been the first person who employed it in voltaic arrangements. It is, however, quite evident from the manner in which he has alluded to it in the Bakerian lecture for,

1826, that he had no idea of its general use in the construction of batteries, he simply mentions the fact, that zinc in amalgamation with mercury is positive with respect to pure zinc.

In the year 1823, Mr. Kemp of Edinburgh inserted an article in Jamieson's Philosophical Journal, describing the manner in which he had constructed batteries of amalgamated zinc and copper; and of his researches we shall endeavour to give a brief abstract.

The author first alludes to the difficulty which many persons have experienced in making experiments upon voltaic electricity and electro-magnetism, in consequence of being unable to incur the expense of purchasing suitable apparatus. In performing the most important experiments, different sets of batteries are required according to the nature of the substances to be acted upon. But even when batteries have been obtained, the student has always been subject to delay, inconvenience, and even failure, in consequence of the rapid oxidation of the zinc plates, which renders them useless in voltaic arrangements long before the batteries are worn out.

KEMP'S PILE WITH MERCURY.

"It had frequently occurred to me," says Mr. Kemp, "that mercury might be used as one of the metals for forming galvanic apparatus, and from the difficulty with which it is acted upon by most of the acids would answer the purpose of a

negative metal better than any other, gold and platinum excepted, unless its fluidity destroyed its power of exciting galvanic energy."

Mr. Kemp's first apparatus is represented in fig. 85 ; A B C D is a circular wooden cup, half an inch deep and three inches in diameter, with a projecting rim A B. A circular

85.

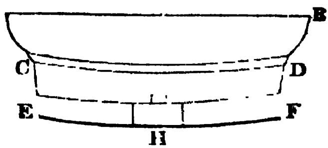
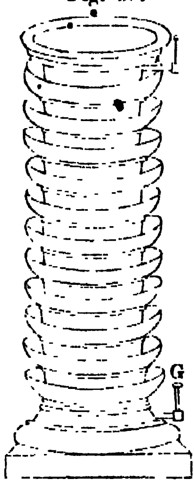


plate of zinc, E F, is attached to the cup, about an inch from it by a copper wire, one end of which passes into the bottom of the cup with a projection of about one-eighth of an inch. The whole of the cup is covered with a coating of wax, care being taken that the wire be left exposed ; and the bottom of the cup is covered with mercury so as to form a sufficient contact with the wire of the zinc plate. The cup is then nearly filled with diluted muriatic acid. In this manner the author obtains a voltaic arrangement of two fluids and one solid, consisting of zinc, mercury, and acid.

In exciting this pile, after the mercury and acid have been poured into the cups, the ternary arrangements are to be placed upon each other as in fig. 86. "The zinc plate of one will then be in contact with the acid contained in that immediately under it, the cup itself resting upon a small cheek cut

round the lower part of the rim. For the purpose of experimenting with this apparatus, a small brass socket, G, passes into the base, and communicates with the mercury in the undermost cup. Into this socket a hole is drilled for inserting the wire. Another is attached to the uppermost plate of the pile from which a wire can be brought to complete the circuit."

Fig. 86.



The object of the author in giving a convex form to the zinc plate is to facilitate the escape of the hydrogen, which would otherwise collect and displace the acid.

"In this arrangement," says the author, "the zinc, as it is acted upon by the metal, is soon corroded, and is liable to the same objections as the ordinary galvanic apparatus. And in a battery where the negative metal is liquid, and the positive solid, no increase of power is obtained over the ordinary apparatus; a circumstance which would seem to indicate that the negative liquid metal acts merely the part of a conductor: nor can it while the positive remains solid transmit the full effect of larger batteries, but must necessarily reduce it in the same proportion as a solid pile. The effect, however, would be very different were the positive plate liquid, and the negative solid. This I have endeavoured to accomplish by the following arrangement, in which the positive plate is an amalgam of mercury and zinc."

KEMP'S AMALGAM PILE.

The form of this pile is the same as that already described, with this difference, that instead of pure mercury, copper is used as the negative plate; and instead of zinc, an amalgam of zinc and mercury is the positive one: and whether we take into consideration the new field it opens for tracing the laws governing galvanic action, its powerful effects on the magnet and in the combustion of metal, or the rapidity with which it decomposes imperfect conductors, this instrument must be acknowledged of some importance.

A B C D, (*see* fig. 85,) represents a circular wooden cup half an inch in depth and three in diameter, having a projecting rim A B. H is a small button of wood turned on the bottom of the cup at its centre, and projecting one-eighth of an inch from it. E F is a circular plate of copper attached to the cup by means of a wire of the same metal on which a screw is formed. The wire passes through the cup and screws into a brass nut which is sunk into the inside of it, the copper plate being kept at its proper distance by the button of wood. The hole is rendered tight by a coating of wax, care being taken to keep the nut and the projecting point of the wire uncovered.

The copper plate is perforated with holes to allow the hydrogen, as it is formed at the surface of the zinc and mercury, to pass up through it and escape. A plate of wire gauze, or a copper wire coiled round, so as to form a plate,

will answer the purpose equally well, as it allows the hydrogen to pass freely through the interstices.

A quantity of liquid amalgam of zinc and mercury, merely sufficient to cover the bottom, is to be poured into the cup, which will be in contact with the copper plate E F, through the medium of the nut and wire. Over this is poured as much dilute muriatic acid as will nearly fill the cup. In this manner we obtain one complete combination, consisting of copper, the amalgam of mercury and zinc, and the acid.

The amalgam of zinc and mercury in this arrangement becomes the positive plate, while the copper is rendered negative.

To form the amalgam small pieces of zinc with about four times the weight of mercury, must be placed in a crucible, and exposed to the action of an intense heat, any quantity of mercury required being added when the metals are united. When thus prepared the amalgam may be kept for any length of time in earthen or glass vessels, which exclude it from the action of the atmosphere. After continued use the zinc will be expended; but so long as any portion of this metal remains in combination with the mercury, the pile will continue in activity, and afterwards the same process of amalgamation may be easily repeated.

The fluid medium used by Mr. Kemp consisted of one part of muriatic acid, two of muriate of soda, and ten of water. Each cup of an intended pile is first charged with the amalgam, which need not be more than sufficient to cover the bottom of the vessel; upon which is poured the fluid medium. To form a pile of this construction, a series

of these alternations must be placed upon each other as in fig. 86; the copper plate of each being in contact with the acid of that beneath it.

One of the most important advantages of this pile is, that it may remain a long time in action without any decrease of galvanic action. In the common arrangement of zinc, copper, and dilute acid, the full energy of the battery is only obtained at the instant the plates are immersed, for at the termination of each successive period, the power is less than at that preceding. "This seems," says Mr. Kemp, "to depend upon the particles of zinc, which having perfect freedom of motion in the mercury, are attracted by the copper plate with which they are in contact, through the medium of the wire, and by this means, the mercury alone is exposed to the acid, which has no action upon it. But upon the destruction of the electrical tension, by completing the circuit, the particles of zinc are no longer attracted by the copper plate, and having perfect freedom of motion in the mercury, rise to the surface, are acted upon by the acid, and have again a tendency to restore the pile to its former state of tension. It will thus be perceived, that the action going on in the pile, and, consequently, the quantity of electricity evolved, are each in exact proportion to the conducting power of the substance employed to complete the circuit." In the common arrangement the metal is, as we have already seen, soon oxidated, but in this, little or no oxide is formed on the amalgam, for the particles of zinc are immediately taken up by the acid.

From an article in the Annals of Electricity, we learn that

Mr Sturgeon also made some experiments on this subject, the results of which were published in 1830, in his Experimental Researches. Without examining with any degree of minuteness this paper, we may be permitted to make one quotation from it, as calculated to give the reader a just conception of the probable value of amalgamated zinc in voltaic arrangements. "Were it not on account of the brittleness, and other inconveniences occasioned by the incorporation of the mercury with the zinc, amalgamation of the surfaces of zinc plates in galvanic batteries would become an important improvement; for the metal would last much longer, and remain bright for a considerable time, even for several successive hours—essential considerations in the employment of this apparatus.

"Notwithstanding the inconvenience, however, the improvement afforded by amalgamating the surfaces of zinc plates, becomes available in many experiments; for the violent and intense chemical action which is exercised on zinc by a solution of sulphuric or muriatic acid, with the consequent evolution of heat, and annoying liberation of hydrogen have no place when the plates are amalgamated. The action is tranquil and uniform, and the disengagement of the gas, which is trifling, occurs only when the circuit is complete, and at the surface of the copper plate only. The electric powers are highly exalted, and continue in play much longer than with pure zinc; and the only care of the experimenter is to prevent the copper, or whatever metal be substituted, from becoming amalgamated."

M. Masson recommends, in the Annales de Chimie, the

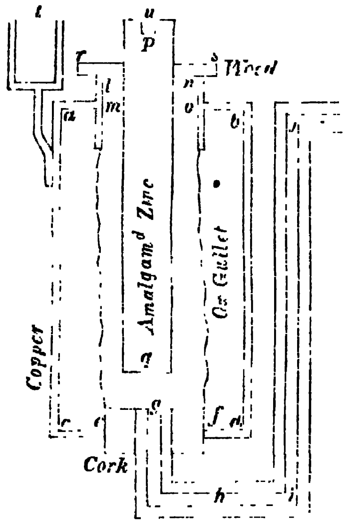
following simple method of preparing amalgamated zinc plates for voltaic arrangements. After having placed on the zinc a little mercury, pour upon it dilute sulphuric acid, and rub the mercury over the surface of the zinc with a piece of linen. The amalgamation goes on very rapidly, if a small quantity of dilute acid be occasionally added.

PROFESSOR DANIELL'S BATTERY.

The importance of obtaining the best possible arrangement for the production of voltaic electricity is so evident, that we need not make any apology for the introduction of a few extra pages on this subject, and especially for a short account of Professor Daniell's battery. Fig. 87, is a sectional drawing of Daniell's battery, and we shall follow the inventor's description as nearly as possible. *a b c d* is a cylinder of copper, six inches high and three and a half wide, open at the top *a b*, and closed at the bottom *c d*, except a collar *e f*, one and a half inch wide, intended for the reception of a cork, into which a glass syphon tube, *g h i j k*, is fitted. On the top *a b*, a copper collar, corresponding with the one at the bottom, rests by two horizontal arms. A membranous tube is drawn through the lower collar *e f*, where it is fastened by a cork, a communication being left open with the syphon tube, so that when filled to the level *m o*, the liquid may flow out at *k*. The upper part of the membrane *l m n o* is fastened with twine. The syphon tube is attached when the membrane has been fixed. Various connections of the copper

and zinc of the different cells may be made by means of wires proceeding from one to the other."

Fig. 87.



The arrangement ultimately adopted by Professor Daniell is described as follows, in a letter addressed to Dr. Faraday. "The increase of the number of the battery series requires, for convenience, a different arrangement from that I described in my last communication; and I now place the cells in two parallel lines of ten each, upon a long table, the syphon tubes arranged opposite to each other, and hanging over a small gutter, placed between the rows, to carry off the refuse solution when it is necessary to change the acid; and as the uniformity of action may be completely maintained by the

occasional addition of a small quantity of fresh liquid, I have been able to dispense with the cumbrous addition of the dripping funnels. This arrangement admits with facility of any combination of the plates which may be desired."

MR. MULLINS' SUSTAINING BATTERY.

Without entering into the dispute between the friends of Professor Daniell and Mr. Mullins as to the priority of invention in the introduction of the sustaining battery, we shall now give the description of the instrument proposed by the latter gentleman in his own words, referring the reader for further information to the original article[1].

"The battery I generally use for my own purposes consists of ten pots each, containing a single arrangement, and constructed in the following manner. Close to the inner surface of an earthenware pot four inches high, and two and a half wide, is fitted a cylinder of zinc, the depth of which is about a third of the depth of the pot: a small piece of zinc, about half an inch wide, rises above the level of the remainder, about an inch; and to this is soldered a narrow ribbon of copper, which rises to the top of the pot, and projects over it about five inches, for the purpose of communicating with a mercurial cup. Within this cylinder of zinc, and as close to its surface as possible, stands a copper vessel the height of which equals the depth of the pot. This vessel is two

[1] Annals of Electricity, vol. i. p. 205.

and a quarter inches wide, and has either a wooden or copper bottom, water-tight. Round the upper edge of this cylinder, and external to it, is soldered a rim of copper about a quarter of an inch wide, on the outside of which is formed a groove all round: in the upper surface of this rim are two holes as large as it will allow, for the purpose of drawing off the charge or supplying it. The copper cylinder thus constructed is placed upon a flat circle of cork, open in the centre, and projecting as much from the outer surface of the copper below, as the rim does above: this cork is bound round with strips of membrane, and a thin calf or pig's bladder previously steeped in tepid water is drawn over the cylinder, the use of the cork being to preserve the membrane from contact with the copper: the bladder is drawn tight and fastened by a string round the groove in the rim before described. A narrow band of copper is soldered to the upper edge of the cylinder, and the battery is now fit for use. In charging it I use two solutions: that in contact with the zinc being one part of a saturated solution of muriate of ammonia to five of water, and that in contact with the copper a saturated solution of sulphate of copper."

Before we close our remarks on the instruments employed in the production of voltaic electricity it will be necessary to refer the reader to the manner in which the sustaining batteries are now connected, a plan proposed by Mr. Clarke, and as it appears, by far the most convenient yet adopted. The battery is represented in the diagram at the head of this chapter, and consists of ten jars arranged in parallel rows, in a case having a partition dividing it lengthways into equal

parts. Upon the partition is fixed a series of circular blocks filling the spaces between the jars. In each block four holes are formed to contain mercury, and take the conducting wires. Fig. 88, is a plan of the arrangement of the wires, those from the zinc plates being in the line *e*, and those from the copper in the line *f*.

Fig. 88.

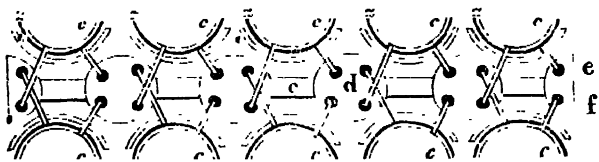


Fig. 89, is a sectional drawing of this method of forming the connections. It is called the intensity conductor, and consists of a slip of mahogany to which copper wires are attached, the copper and zinc elements being connected alternately throughout the series.

Fig. 89.

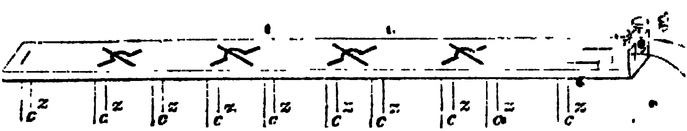
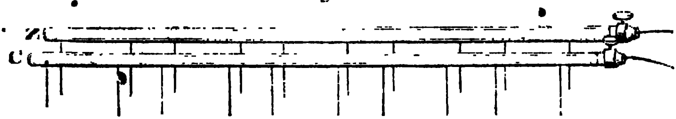


Fig. 90, represents the quantity-conductor, which consists of two brass rods with wires, so attached as to fall into the mercury cups. By using this method of conduction all the copper elements are united together, and at the same time

all the zinc, forming an instrument called a calorimoter, an arrangement first described by Professor Hare of America, and deriving its name from its great calorific power.

Fig. 90.



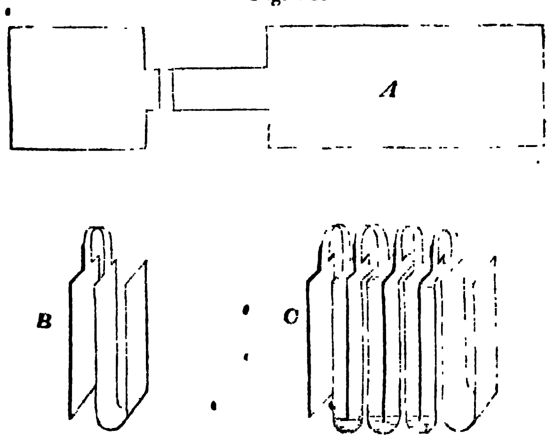
FARADAY ON THE BATTERY.

In the tenth series of Electrical Researches, Dr. Faraday has made some remarks on the battery of which we must give a general account before we attempt to speak of the effects to be obtained from the electricity it developes. The chemical forces of a voltaic arrangement are divided into two portions, the one is local and is lost, the other is transferred round the circle, and constitutes the electric current of the instrument. In the open battery all the action is local; and in the ordinary battery much is lost, even when the circuit is completed; but in an arrangement described by the Doctor, "all the chemical power circulates and becomes electricity."

If a voltaic circuit were formed of zinc and platina, the latter surrounding the former, as in the double copper arrangement, dilute sulphuric acid being used, no insulating division would be required. The resistance to the passage of the current at the place of decomposition would stop the current, and act as insulation to the electricity of contiguous plates.

Dr. Faraday proposes an arrangement consisting of zinc plates, surrounded by copper, similar to Wollaston's battery; the distance between the metallic surfaces being about the thickness of paper. His copper plates are separated by thin veneers of wood. The zinc plates were cut from rolled metal, and had the form represented at A in fig. 91, "They were bent over a gauge into the form B, and when packed into the wooden box, constructed to receive them, were arranged as in C; little plugs of cork being used

Fig. 91.



to keep the zinc plates from touching the copper plates, and a single or double thickness of cartridge paper being interposed between the contiguous surfaces of copper to prevent them from coming in contact. Such was the facility afforded by this arrangement, that a trough of fifty pairs of plates could be unpacked in five minutes, and repacked again in

half an hour, and the whole series was not more than fifteen inches in length."

A trough consisting of forty pairs of three-inch plates of the new arrangement, was found to be quite equal to forty pairs of four-inch, constructed after the old arrangement, in the ignition of platina wire, in the discharge between charcoal points, and in giving a shock.

Dr. Faraday performed a series of ingenious experiments to ascertain the quantity of metal oxidized and dissolved by the two different arrangements, and by them he is brought to the conclusion that "no doubt can remain of the equality, or even the great superiority of this form of voltaic battery over the best previously in use, namely, that with double coppers, in which the cells are insulated. The insulation of the coppers may, therefore, be dispensed with; and it is that circumstance which principally permits of such other alterations in the construction of the trough as gives it its principal advantages."

The doctor then proceeds to state the advantages and disadvantages of the arrangement, but our space will not allow the mention of these. He has also shewn that the battery is better charged with nitric than either sulphuric or muriatic acid, and that nitric acid with the sulphuric may be advantageously employed. Two hundred parts of water, four and a half of oil of vitriol, and four of nitric acid is recommended as the best liquid. From other experiments by the same philosopher it appears, that the loss of zinc plate is not according to the strength of the acid. When eight parts of nitric acid was used with two hundred of water, each plate

lost 1·854 equivalent of zinc, when sixteen parts, 1·82 equivalent,—when thirty-two parts 2·1 equivalents.

The purity of the zinc is of the greatest importance, "most zincs when put into sulphuric acid leave more or less of an insoluble matter upon the surface in the form of a crust, which contains copper, lead, iron, &c. in the metallic state." No gas should rise from the zinc plates; the larger the quantity generated on these surfaces the greater is the local action. Rolled Leige or Mosselman's zinc is the best.

It may be still further stated that when the zinc and copper plates are near, a greater force is gained than when they are far apart. Whatever retards the circulation of the electricity, increases the proportion of that which is local, and of course decreases the amount of that which is transferred round the circle. The liquid has this retarding force, and therefore weakens the power of the battery.

Many other Voltaic arrangements have been proposed, all of which are in some degree worthy of attention, and some of them exceedingly valuable. We have, however, already devoted as many pages to the subject as seemed consistent with the character of this book, and the importance of the subject. We might now proceed at once to consider the effects of voltaic electricity as classed under the general heads physiological, chemical, luminous, heating, and magnetic; but if we may premise that water as well as many other substances are capable of chemical decomposition, there can be no objection to the mention in this place of an instrument by which Dr. Faraday proposes to test the power of voltaic batteries.

FARADAY'S VOLTA-ELECTROMETER.

"I consider," says this acute observer, "the foregoing investigation[1], as sufficient to prove the very extraordinary and important principle with regard to water, that when subjected to the influence of the electric current, a quantity of it is decomposed exactly proportionate to the quantity of electricity which has passed, notwithstanding the thousand variations in the conditions and circumstances under which it may at the time be placed; and further, that when the interference of certain secondary effects, together with the solution or re-combination of the gas and the evolution of air, are guarded against, the products of the decomposition may be collected with such accuracy, as to afford a very excellent and valuable measurer of the electricity concerned in their evolution."

Dr. Faraday consequently proposed some instruments, by the use of which, with a voltaic arrangement, water may be decomposed, and the quantity of electricity determined by the volume of the gases. "In many cases," he says, "when the instrument is used as a comparative standard, or even as a measurer, it may be desirable to collect the hydrogen alone, as being less liable to absorption or disappearance in other ways than the oxygen; whilst at the same time its volume is so large as to render it a good and sensible indicator." There are, however, "two general forms of the instrument

[1] See 7th Section of Experimental Researches.

which I submit as a measurer of electricity. One, in which both the gases of the water decomposed are collected; and the other, in which a single gas, as the hydrogen only, is used. When referred to as a comparative instrument, it will not often require particular precaution in the observation; but when used as an absolute measurer, it will be needful that the barometric pressure and the temperature be taken into account, and that the graduation of the instruments should be to one scale; the hundredths and smaller divisions of a cubical inch are quite fit for this purpose, and the hundredth may be very conveniently taken as indicating a degree of electricity."

A modification of this instrument we have been for some time past in the habit of using, and have found it a most important aid in ascertaining the relative quantity of electricity obtained from different batteries. An anonymous writer has, however, attacked Dr. Faraday, and charged him with the appropriation of an invention made by, and belonging to another. The name of Faraday is, and ever will be, so associated with the progress of the science of electricity, and to the honour of our country, that we shall not step far out of our path, even in an introductory work, by enquiring into the truth of the accusation. This we shall do with the more confidence, because some historical information will be, at the same time, communicated to the reader.

The charge is made upon the faith of the following passage from Donovan's Galvanism. "Robertson also describes an instrument, the principle of which has been since frequently used for measuring the decomposing energy of any

galvanic series. It consists of a tube of glass filled with water, and containing a wire at each end, which comes very near the other within. The tube stands vertically, and is graduated at its upper end, so that the water is resolved into gases, the quantity of which, being ascertained by the scale, gives, when compared with the time, the energy of the series."

The ambiguous manner in which the last sentence is expressed is calculated to mislead the reader, or at least to give an opportunity for a double construction—whether it was the quantity of water decomposed, or of the gas into which it was resolved, that was taken by Robertson as a measurer of Voltaic energy does not appear. The following translation from the original memoir will prove that it was the former.

" When a science advances, and its principles begin to be developed, it requires a variety of apparatus, and much attention in pursuing the study, so as to distinguish reality from appearances. In galvanic experiments an instrument has been much wanted, sufficiently delicate to enable experimenters to observe the *presence*, *course*, and especially the *action* of this fluid. In the absence of new discoveries, and until deeper researches produce one more perfect, a description of that which I employ may be useful. It consists of a tube eight inches long, and one-twelfth of an inch bore, to contain water. Into one of its extremities is inserted a piece of zinc, and into the other a piece of silver, which extend to within an inch of the centre of the tube. That part of the glass which contains the zinc is divided into a scale of one-

tenth of a line, and at this end of the tube is a cock by which water is introduced, and from which, *when the apparatus is in action, the air escapes.*

"In making use of this instrument it must be placed within the galvanic circle or current, and the bubbles which appear at the extremity of one of the pieces of metal indicate the presence of the fluid, and the increase or diminution of the quantity of these bubbles, is denoted by the divisions marked on the scale. Thus, by noting the time, the greatest and least activity of the galvanic current may be ascertained.

"This instrument appears to me to indicate very correctly the appearance and progression of the current, by which the stream of bubbles, sometimes flowing from both pieces of metal, is produced. It may perhaps embarrass philosophers to account for the current having this effect on both pieces of metal:—it may be caused by the nature of the metals, their quantity or quality, or even by the hygrometric or barometric state of the atmosphere."

From this account it is quite evident that the instrument was intended as a measurer of Voltaic action by the decomposition of water; and so far Dr. Faraday was preceded by Robertson. Whether he was aware of this or not, is scarcely a matter of doubt, for there is no philosopher in the present day more willing to acknowledge and give full merit to the discoveries of his contemporaries. In what other point there is the slightest resemblance between the instruments proposed by Faraday as measurers of Voltaic electricity, and that used by Robertson we cannot discover. In the latter,

Voltaic action was determined by a diminution in the bulk of water, for the tube was filled, and the stopcock was left open, that the gases might escape: in the former by the gases obtained from decomposition. But it must also be remembered that Dr. Faraday was not led to the invention of his instrument by any loose conjecture, or a recollection of any previous instrument, for he reasons from a principle. He had previously ascertained that the decomposing action of a current is constant, for a constant quantity of electricity, whatever may be the circumstances under which the electricity is acting; and directed by this law, he endeavoured to construct a suitable instrument to measure the subtle agent.

PHYSIOLOGICAL EFFECTS.

The physiological effects resulting from the passage of Voltaic electricity through the animal body, were the means of introducing the agent itself to the attention of philosophers. The circumstances under which the first experiments were made, the theories that were formed, and the construction of the battery, have been already mentioned. As the size of the battery, or rather the number of alternations was increased, the effects became more striking; animals of a large size and even the human body were made to exhibit contractions so violent, as even to be terrific to the spectator; the convulsive muscular motion giving all the indications of excessive agony, and of returning life.

Similar experiments have been made both in this and in

other countries upon the bodies of criminals immediately after their execution. Aldini operated with a great number of plates upon the body of a man who had been executed at Newgate, and succeeded in producing violent agitation of the limbs. But the most remarkable experiments were those made by Dr. Ure on a malefactor at Glasgow. A pointed rod connected with one end of the battery was introduced into the neck, while another rod from the opposite end of the battery was connected with the heel, and the knee being previously bent, the leg was thrown out with such violence as nearly to overturn one of the assistants. The muscles of respiration were, afterwards put into action by directing the fluid through the phrenic nerve. The head was then brought under the influence of the Voltaic current, and the muscles were dreadfully contorted. Rage, horror, despair, anguish, and ghastly smiles united in giving a hideous expression to the face; and many of the spectators were so affected that they were compelled to leave the apartment, fearing that life would be ultimately restored.

Every kind of animal appears to be susceptible of the influence of Voltaic electricity. The fishes and vermes are peculiarly sensitive. Humboldt says he has seen fishes, the heads of which had been cut off half an hour, strike with their tails when galvanized in so forcible a manner, that the whole of the body was raised considerably above the table on which they were placed. Some of the vermes also exhibit their excitability under the action of the fluid in a very decided manner. It is easy to prove that a current of extreme weakness has a great effect upon some animals, by placing a

leech upon a plate of zinc, and bringing a plate of copper (touching the zinc in some point,) in contact with it: the animal will instantly recoil as if it had experienced a shock. The same effect will not be produced if it be placed on either zinc or copper alone.

From this experiment it will be evident that living bodies are acted upon by the Voltaic fluid as well as those which are dead. This may be proved with a very small battery; but it must be remembered that the amount of action is governed by the number, and not the size of the plates. On account of the small tension of the Voltaic electricity, which, however, may be increased by an addition to the number of alternations, the skin, a very imperfect conductor, should be moistened with water. With a single pair of plates, however large, no violent physiological effect can be obtained, for although a large quantity of electricity may be developed by them, it has no intensity. So on the other hand a number of plates, however small, and containing not one-twentieth part of the metal in the single pair, may give a violent shock.

Whether the administration of Voltaic electricity as a medical agent is not in some diseases desirable, is no longer a matter of doubt. It was, we believe, first proposed by Aldini as a suitable agent for the restoration of suspended animation. "I am far from wishing," he says, "to raise any objection against the administration of other remedies which are already known. I would only recommend galvanism as the most powerful means hitherto discovered of assisting and increasing the efficacy of every other stimulant." Since the

time of this electrician the agent has been applied for many other medical purposes, and has often been found effective. The trouble attending its use, and the very speedy exhaustion of the power of the battery when constructed according to the old system, were, however, impediments to its general introduction. The common electricity, applied in a quiet manner, was, therefore, generally preferred. When the agent was first employed in the cure of diseases, it was thought that every thing was to be done by shocks—by discharging accumulated electricity through the body, or through such parts of it as might be affected. If a sudden and unnatural action should be ever required, it may easily be obtained in this manner; but whenever the effect is to be produced on the system, and the action is to be that of the fluid itself, the person of the patient must be, as it were, filled with electricity, by placing him on an insulating stool, to be afterwards drawn away by a director communicating with the ground. Both the common and Voltaic electricity will, in all probability, be superseded, for this purpose, by the magnetic, as the instrument from which it is supplied is portable, and may in a few minutes be put in action.

PRODUCTION OF INSECTS.

The attention of electricians has been recently drawn to the remarkable appearance of certain insects during the performance of some experiments on electrical crystallization by Mr. Crosse. Although but little is at present known

concerning the formation of these creatures, it is necessary we should describe the experiments which have been made, and it may be done with most propriety in this place, as the facts will belong to the present section if it should be ultimately found that electricity is in any way influential in their production. In the Transactions of the Electrical Society Mr. Crosse has explained his experiments, and the results he obtained, and if his memoir were not too long for quotation, we should introduce it in preference to the condensed account we have drawn from his interesting paper. It will, however, be our object to follow him, and even his phraseology, as closely as our limited space will admit.

In attempting to form artificial minerals by long continued electric action on fluids, holding in solution such substances as were necessary for the particular purpose, Mr. Crosse adopted a variety of contrivances to secure a constant current of electricity, and to expose the solution to the electric action in a manner best suited to effect his object. "Amongst other contrivances," he says, "I constructed a wooden frame, of about two feet in height, consisting of four legs projecting from a shelf at the bottom supporting another at the top, and containing a third in the middle. Each of these shelves was about seven inches square. The upper one was pierced with an aperture, in which was fixed a funnel of Wedgwood ware, within which rested a quart basin on a circular piece of mahogany placed within the funnel. When this basin was filled with a fluid, a strip of flannel wetted with the same was suspended over the edge of the basin and inside the funnel, which acting as a syphon, conveyed

the fluid out of the basin through the funnel, in successive drops. The middle shelf of the frame was likewise pierced with an aperture in which was fixed a smaller funnel of glass, which supported a piece of somewhat porous red oxide of iron from Vesuvius, immediately under the dropping of the upper funnel. This stone was kept constantly electrified by means of two platina wires on either side of it, connected with the poles of a Voltaic battery of nineteen pairs of five-inch zinc and copper single plates, in two porcelain troughs, the cells of which were filled at first with water, and $\frac{1}{300}$ of hydrochloric acid, but afterwards with water alone. I may here state, that in all my subsequent experiments relative to these insects, I filled the cells of the battery employed with nothing but common water. The lower shelf merely supported a wide mouthed bottle to receive the drops as they fell from the second funnel. When the basin was nearly emptied, the fluid was poured back again from the bottle below into the basin above, without disturbing the position of the stone. It was by mere chance that I selected this volcanic substance, choosing it for its partial porosity; nor do I believe it had the slightest effect in the production of the insects to be described."

The following is the manner in which Mr. Crosse made the fluid with which he filled the basin. A piece of black flint being raised to a red heat, and afterwards suddenly cooled in cold water, was reduced to powder. Two ounces of this was then mixed with six ounces of carbonate of potassa, and exposed in a blacklead crucible to an intense heat. The compound was then poured on an iron plate, and

while warm reduced to a powder, after which boiling water was poured on it, and kept boiling for some minutes; by which the greater part of the soluble glass thus fused was taken up by the water. To a portion of the silicate of potassa, "boiling water was added to dilute it, and hydrochloric acid was slowly added to super-saturation."

"My object," says Mr. Crosse, "in subjecting this fluid to a *long* continued electric action through the intervention of a porous stone, was to form, if possible, crystals of silica at one of the poles of the battery, but I failed in accomplishing this by those means. On the fourteenth day from the commencement of the experiment, I observed, through a lens, a few small whitish excrescences or nipples projecting from about the middle of the electrified stone, and nearly under the dropping of the fluid above. On the eighteenth day these projections enlarged, and seven or eight filaments, each of them longer than the excrescence from which it grew, made their appearance at each of the nipples. On the twenty-second day these appearances were more elevated and distinct, and on the twenty-sixth day each figure assumed the form of a perfect insect, standing erect on a few bristles which formed its tail. Till this period I had no notion that these appearances were any other than an incipient mineral formation; but it was not until the twenty-eighth day, when I plainly perceived these little creatures move their legs, that I felt any surprise; and I must own that when this took place I was not a little astonished. I endeavoured to detach, with the point of a needle, one or two of them from their position on the stone, but they immediately died, and I was

obliged to wait patiently for a few days longer, when they separated themselves from the stone and moved about at pleasure, although they had been, for some time after their birth, apparently averse to motion. In the course of a few weeks about a hundred of them made their appearance on the stone. I observed that at first each of them fixed itself for a considerable time in one spot, appearing as far as I could judge to feed by suction; but when a ray of light from the sun was directed upon it, it seemed disturbed, and removed itself to the shaded part of the stone. Out of about a hundred insects not above five or six were born on the south side of the stone. I examined some of them with a microscope, and observed that the smaller ones appeared to have only six legs, but the larger ones eight. I have had three separate formations of similar insects at different times, from fresh portions of the same fluid, with the same apparatus."

Some specimens of the insects were sent by the Royal Society to the French Academy, and, according to the report drawn up by some of the members, they belong to a new species of the genus Acarus. Of this report Mr. Crosse has much reason to complain, for it is dictated by an unenquiring scepticism, scarcely less than disgraceful to those who call themselves scientific observers.

With regard to the origin of the insects neither Mr. Crosse nor any of the scientific gentlemen who have seen the animals, have ventured an opinion. The experiments hitherto made do not at present warrant the expression of any theory. It has been supposed by some persons that the

insect is a native of the water used by the experimenter, but since writing the account from which we have extracted, Mr. Crosse has succeeded in obtaining the insects on a bare platina wire plunged into fluo-silicic acid, one inch below the surface of the fluid at the negative pole of a small battery of two inch plates in cells filled with water. This is, as he states, a singular fluid for these insects to breed in, who seem to have a flinty taste, although they are by no means confined to silicious fluids; but as the acid was procured from London, the fact disproves the supposition to which we have referred.

LUMINOUS EFFECTS.

We have seen that the passage of ordinary electricity through air, is always attended with the evolution of light. A similar appearance is readily obtained from the Voltaic battery, provided that a sufficient number of plates be used. Voltaic electricity is also capable of producing a luminous effect in its passage through a receiver, containing rarefied air. The cause of the splendid appearance presented by the transit of electricity from one charcoal point to another under these circumstances, will be immediately perceived from the observations that have been made concerning the same phenomenon by ordinary electricity. The Voltaic fluid possesses little or no intensity, and on this account it cannot be made to strike from one conductor to another, when separated by a distance of a few inches; for the density of the atmospheric air is sufficient to restrain it. But when the in-

tervening air is rarefied, it presents less opposition, and the electricity darts from one conductor to the other, producing a splendid arc of light.

For the production of luminous effects by Voltaic electricity, many things are to be considered. The thickness and length of the conducting wire, the quantity of electricity to be conducted, the temperature of the wire and the surrounding medium, the intensity of the electricity, and the kind of metal employed for the conduction, have an influence in modifying the effects, which will be greater or less in proportion to the attention paid to these conditions.

It is thought by some persons that the Voltaic light will be, at some future period, applied in those cases where a strong and brilliant illumination is required. This has been hitherto prevented by the rapid exhaustion of the batteries, and the necessity of supplying fresh charcoal. One of these objections has been already virtually removed, and the other may be. The Voltaic light is more intense than that obtained from the oxy-hydrogen microscope, and if it could be made generally available would altogether supersede that dangerous instrument, and give the careless instrument-maker one opportunity less of defrauding and endangering the lives of his customers. One of these instruments was purchased, soon after the introduction of the present arrangement, by a gentleman with whom we have long been on terms of friendship, at a large price, from a *respectable* maker. The instrument was tested, and was found to be an ill-constructed apparatus, and scarcely safe for any person to use; it was, in fact, so made that an

apprentice boy of fifteen years of age might have been ashamed to call the work his own. We would strongly caution our readers against the instruments usually vended, —they are made to enrich the maker, and are for the most part unfit for use. Hundreds of them have been made and sold, but we doubt if many of the purchasers can use them with confidence. We repeat again, and with a certainty that our opinions will coincide with those of the persons who are accustomed to use the oxy-hydrogen microscope, they are troublesome and dangerous, ill-constructed and inefficient. If the reader should require one for his own use, it may be made under his superintendence, and in a careful and proper manner. It will, however, be well when the instrument can be done away with altogether, and the Voltaic light be employed in its stead. Should electricians succeed in using this agent for such a purpose, it will also be well suited for light-houses, and also perhaps for the illumination of large buildings.

HEATING EFFECTS.

The calorific effects of Voltaic electricity are far greater than those of the electrical battery; and there is a singular difference between the operation of the two. In the case of ordinary electricity; calorific effects are never produced except when the restoration of the electric equilibrium is suddenly produced; and there is reason to believe that the rise of temperature is even then greatly attributable to the mechanical

concussion of the particles of the conducting body. But Voltaic electricity produces the effect by the mere passage of the electricity through conducting bodies when the circuit is complete. If a fine iron wire of moderate length be made the medium of connexion between the poles of a large battery, it may be ignited to fusion. Steel wire burns brilliantly under the same circumstances. Nor is there any limit to the evolution of heat as long as the battery maintains its power. The effects in this instance would, therefore, appear to be the result of the mere passage of an equal and continuous current of the electric fluid, and must be traced to its direct influence in raising the temperature of the conducting body, and not to the agency of mechanical concussion.

The order in which metallic wires are raised to a red heat by Voltaic electricity, was determined by Mr. Children with his large battery, to be, platina, iron, copper, gold, zinc, and silver. From the experiments made by this gentleman upon the metal conductors, he was led to the discovery of the law, that the facility with which the metals are ignited vary inversely as their conducting power for electricity.

The heating action of Voltaic electricity may be exhibited upon the leaves of metals, with considerable effect. When they are made the medium of communication between the poles of a powerful battery, they are deflagrated, burning with great brilliance. Gold leaf burns with a vivid white light, tinged with blue; silver with an emerald green; copper with a bluish white light.

When a slender iron wire is connected with one pole of a

powerful Voltaic battery, and its end is brought into contact with the surface of mercury connected with the other pole, a vivid combustion of both the wire and mercury is produced, sparks being thrown out in every direction, as rays emanating from a star.

The power of a Voltaic battery in the production of heat, depends upon the quantity of electricity that is transmitted through the wire, rather than its intensity. The number of alternations has, therefore, but little to do with the igniting power of the battery, if a large surface be obtained. It was for this reason that Dr. Hare constructed an instrument of a single pair of plates, and from its great heating power called it a calorimoter. A single pair of Wollaston plates will exhibit the same fact, being capable of developing sufficient heat to increase the temperature of a small platinum wire to redness.

CHEMICAL EFFECTS.

Among all the effects obtained from electricity when acting upon bodies, none are more singular than the production of chemical changes. It is more than probable that neither the composition nor decomposition of compound substances can be produced without the agency of electricity; and it may be doubted whether a change of state can be effected without a development of the same agent. In the vaporisation of water for instance, electricity is given out, as may be easily proved. Take a small tin vessel containing water, and

place it upon the cap of a gold-leaf electrometer. Drop into the water a red hot coal, and vapour will be instantly formed, the leaves diverging and giving evidence of the presence of electricity, the nature of which may be tested by bringing a piece of excited wax or glass near to the apparatus.' In all the great changes produced upon the composition of bodies as exhibited on the laboratory table, and in the theatre of nature the same agent acts a prominent part. The greatest effects are not however produced when the electricity is in a state of the greatest tension. For the production of chemical effects quantity is required, and the Voltaic battery is better adapted to this end than the machine.

The chemical action of Voltaic currents was discovered by the late Mr. Nicholson and Sir Anthony Carlisle in the decomposition of water, by placing it as the uniting conductor between the positive and negative poles of a battery. The effect may be produced by making the metallic wires of the positive and negative poles to pass through opposite ends of a glass tube filled with water, and stopped by corks through which the conducting wires enter, the ends being brought to within about a quarter of an inch from each other. Or the conducting wires may be brought to a vertical tube under a similar arrangement; but in both cases the principle is the same, an intermediate stratum of water being acted upon by the electric current.

Now there are two cases of decomposition of water, that is to say, both the gaseous elements may be obtained in their liberated state, or one (hydrogen) may be collected in its gaseous form, and the other united to one of the solids.

There are also two conditions of the conducting wires which will cause the above results, according as the one or the other obtains.

1. If the wire connected with the positive pole of the battery be formed of an oxidable metal; the oxygen set free by the electrical action will unite with it, and oxidate it, bubbles of hydrogen gas arising at the same time from the wire of the negative pole. Under this condition, only one of the elements of water can be collected.

2. If neither of the wires be oxidable, then both the gases may be obtained by a proper apparatus, the oxygen being in this case left free, from want of a substance with which it may combine.

But in the early experiments made upon the decomposition of water, it was observed that an acid was always formed at the end of the conducting wires, and an alkali at the other. This was observed both by Cruickshanks and Professor Pfaff, who ascribed the origin of the substances to the decomposition of atmospheric air contained in the water, the nitrogen of the air combining with the oxygen of the water on the one hand, forming nitric acid; and with the hydrogen on the other, forming ammonia. Desormes and Simmer also obtained traces of acid and alkali, but supposed them to be muriatic acid and soda. From these singular results it was imagined that muriatic acid and soda were actually generated by the Voltaic current. The opinions of Desormes and of Simmer were afterwards supported, and as it were proved, by a communication, in the Philosophical Magazine for 1805, purporting to have been written by a Mr. Peel of Cambridge.

In this paper it was stated that every precaution being taken to obtain pure water, that which remained after the decomposition of a large quantity by Voltaic electricity, yielded a small amount of muriate of soda, on evaporation. Inquiry was afterwards made to find the writer of this article, but as no person bearing the name attached to the article could be heard of, it has generally been considered as an attempt to impose on the scientific world; for what reason we cannot imagine, as the experiment was found to succeed. But it was still to be determined from what source the muriate of soda was obtained. Theories were not wanting, but they all appeared unsatisfactory, until Davy commenced the examination, which ultimately led him to the discovery of the bases of the alkalies, and those other brilliant results which have given honour to his name, and have made him one of the boasts of Englishmen.

Davy soon discovered that the muriatic acid found in the water, owed its appearance to the animal or vegetable matter employed in connecting the vessels containing the water; for when the fibres of cotton were washed after every process in a weak solution of nitric acid, the presence of the muriatic acid in the water became less easily detected, and at last almost entirely disappeared.

This discovery very naturally led to a suspicion that the soda, in like manner, was produced by the decomposition of some part of the apparatus, and Sir Humphry at last traced it to the decomposition of the glass vessel, at its point of contact with the wire, which was considerably corroded. By employing agate cups, and using very great precautions

to obtain water chemically pure, both the acid and alkali were lost, and oxygen and hydrogen, the two elements of water, were the products.

During the process of the observations that led to these results, Davy discovered that in the decomposition of any neutral salt contained in the aqueous solution, the acid was collected round the positively electrified metallic surface, and the alkali round the negative. Thus if a solution of sulphate of soda, or any other neutral saline compound, be placed in two glass or agate cups, fig. 92; the cups being connected with fibres of moistened asbestos; after a few hours the positive cup will contain a solution of sulphuric acid, and the negative cup a solution of soda. The two elements, therefore, must have been actually transmitted through the water contained in the moistened cotton or asbestos.

Fig. 92.

These results led Sir Humphry Davy to expect that some of the insoluble, or difficultly soluble bodies, might, under the same circumstances, be decomposed, and experiment proved the accuracy of the opinion. Thus two cups of compact sulphate of lime, containing pure water, were connected together by fibrous sulphate of lime moistened with water, and the whole so arranged as to form a part of the Voltaic circuit. After about an hour it was found that the cup connected with the negative wire contained an almost pure and

saturated solution of lime, while that united with the positive wire contained a moderately strong solution of sulphuric acid. Other substances of the same character were tried with equal success, such as the sulphate of strontian, and the fluate of lime.

But it may be considered as a still more singular circumstance, that the effect will be the same in whatever part of the fluid, between the positive and negative wire, the compound substance may be placed. If for instance two cups be used, and the neutral salt, whether earthy or alkaline, be placed in one, and distilled water in the other, the transfer of the element will still take place. If three cups be placed, fig. 93, side by side, connected together by moistened threads of cotton, and sulphate of potash be placed in the middle cup, and blue infusion of cabbage in the other two; the sulphuric acid will collect in the positive cup, and render the infusion red, while the alkali will be transferred to the opposite cup, and tinge the infusion green.

Fig. 93.

A series of still more remarkable circumstances were observed by Sir Humphry Davy while prosecuting these enquiries, for he found that the elements of compound bodies presented to the action of Voltaic electricity, may actually be conveyed through substances that have a strong affinity for them, without evincing the slightest disposition to com-

bine. Let us, for instance, arrange three cups in a series, joining them with moistened cotton. In the cup on the positive side, and in the middle cup, place the infusion of cabbage, the cup on the negative side being filled with a solution of sulphate of soda. Let the arrangement be then placed in the Voltaic circle, and a redness will soon be perceived in the positive cup, which proves that the sulphuric acid is actually transmitted through the infusion of cabbage in the middle glass, without producing any change of colour. By reversing the poles of the battery, the same transfer of the alkali may be made.

Other experiments might be performed to illustrate these principles, but we have mentioned sufficient to prove the general fact, that, by the agency of Voltaic electricity, one class of bodies comprehending hydrogen, the alkaline and earthy bases, and all metallic substances are collected at the negative pole; while oxygen, chlorine, and the compounds in which these elements predominate, such as the acids, are brought to the positive pole.

In the investigation of these interesting results, Sir Humphry Davy was led to the conclusion, that chemical affinity is destroyed, by giving to a body an electricity differing from its natural state, and that the affinity is increased by giving it a greater quantity of its natural electricity. From this he inferred that all those bodies which possess a strong affinity for each other, such as acids and alkalies, are naturally in opposite states of electricity. By inducing, therefore, upon any body, an electrical state contrary to the natural

one, the two substances lose their affinities, and the substances are decomposed. Guided by this theory, Davy succeeded in removing every obstacle to his investigation, and his persevering exertion was crowned with the discovery of the basis of the fixed alkalies.

It had long been supposed that the two fixed alkalies, potash and soda, were compound substances, but every method of analysis that was tried failed to resolve them into their component parts. But notwithstanding the tenacity with which these substances maintained their combination, they failed to oppose the energetic influence of Voltaic electricity.

Sir Humphry Davy succeeded in decomposing these substances in the following manner. A piece of potash being placed on an insulated disc of platina was connected with two hundred and fifty pairs of plates, six inches by four. At the positive pole there appeared a violent effervescence, and at the negative small globules having a highly metallic lustre, and resembling quicksilver, some of which burst with a loud explosion and bright flame, and others were covered with a white film. This substance is the basis of potash, now called potassium, a metal having so strong an affinity for oxygen, that it decomposes water burning vividly.

Soda was decomposed by a similar process, and was proved to have a metallic base, like the vegetable alkali. The gas given off at the positive pole of the battery is oxygen, so that there was no doubt of the alkalies being respectively the oxides of two new metals. The success of these experiments

induced Sir Humphry to investigate the composition of the earths, and although many difficulties for some time opposed him, he was at last equally successful in analyzing them.

Dr. Faraday, who has succeeded Sir Humphry Davy in the public institution with which he was so long connected, has continued the research he commenced, and has been singularly successful in his investigations. To give an abstract of his experiments and opinions would require a greater space than we can now devote to the subject, and especially as he has adopted some new terms which would require explanation. No person, however, who acquires the elements of electrical science will long remain contented without carefully studying his experimental researches, to which we are compelled to refer the reader for further information on the chemical effects of Voltaic electricity.

MAGNETIC EFFECTS.

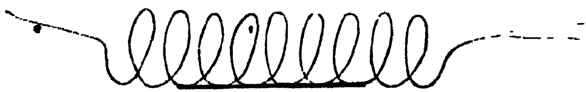
To fully examine the magnetic effect of Voltaic electricity and the relations of electric and magnetic currents, would require a large volume; our only object is to explain a few elementary facts.

Arago proved some years since, that a bar of steel may be magnetized by a current of Voltaic electricity. If a sewing needle, for instance, be placed across a conducting wire, it will acquire the magnetic property, or in other words polarity. Supposing the wire to be placed before the experimenter, the zinc end of the battery being to his left hand,

the point of the needle most distant from him will be the north when above the conducting wire, and south when below.

But there is another way in which a needle may be magnetized:—that is, by placing it in a spiral conducting wire or helix, as represented in fig. 94.

Fig. 94.

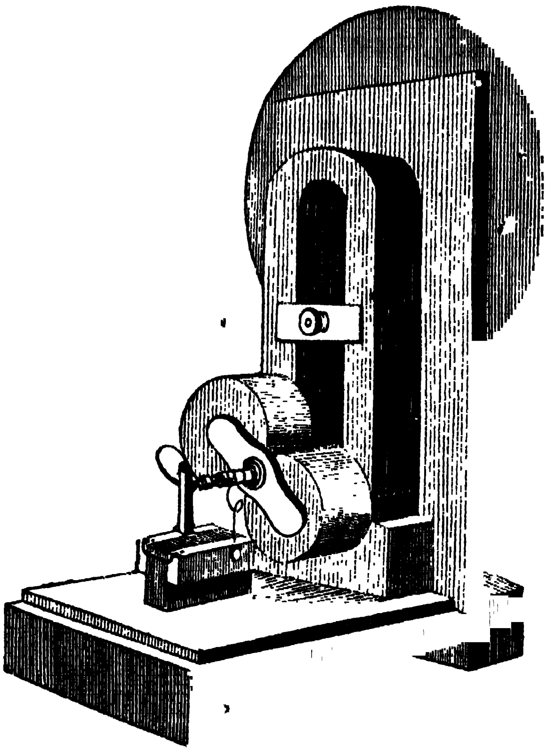


Immediately the connexion is made with the battery, the needle becomes strongly magnetic, having its north pole towards the zinc end, and its south towards the copper. In performing this experiment Mr. Barlow employed a glass tube about five inches long, and half an inch in diameter. When the spiral was previously connected with the battery, the needle was drawn to the centre of the tube, if so placed as to project considerably beyond the end, and would even remain suspended in the middle if the tube was held in a vertical position.

Dr. Faraday made a very interesting experiment, showing the effect of a spiral conducting wire upon a floating magnetized needle. Suspend a helix within a basin of water, allowing the water to rise to its axis. Fix to a cork a small magnetized needle, and place it on the water near to the spiral, in the front of which it will quickly arrange itself and suddenly dart into the interior of the tube, and after a few vibra-

tions become stationary in the centre. The same pole will not, as may be imagined, enter first at both ends;—the position of the needle will be governed by the direction of the whirls of the spiral, and the pole of the battery to which it may be applied. The reader must not suppose that the effect is to be traced to the induction of magnetism in the spiral wire, for if such were the case the needle would be drawn to one end; it is due to the influence of the Voltaic current when circulating in the conducting wire.

The influence of a Voltaic current upon permanent magnetism was first exhibited by Professor Œrsted. This celebrated philosopher discovered that the direction of a magnetic needle delicately suspended was influenced by a current of electricity circulating in a conducting wire, when placed near it, whatever the position might be. This fact attracted the attention of scientific men, and in an incredibly short time an immense number of discoveries were made, and a new science, called Electro-magnetism, sprung up. We have, however, explained as fully as our pages admitted some of the elementary principles of Voltaic electricity, and are compelled to pass over in silence the collateral branch of study.



CLARKE'S MAGNETIC MACHINE.

CHAPTER IX.

MAGNETIC AND THERMAL ELECTRICITIES.

THE magnet is a third source of electricity, for electric currents are set in motion whenever contact is formed and broken between an armature, surrounded by copper-wire, and the magnetic poles. The identity of these currents with the

electricity of the machine and battery is proved by the production of a spark, the heating of metallic wires, chemical decomposition, and other effects commonly resulting from the communication of that fluid. To Dr. Faraday we are indebted for the discovery of magnetic electricity, by obtaining the spark. It was at first thought to differ from both common and Voltaic electricity, having neither the intensity of the one, nor the quantity of the other; it was indeed doubted whether it had any degree of tension until M. Pixii, by the use of an ingenious apparatus, succeeded in obtaining a considerable divergence of the gold leaves.

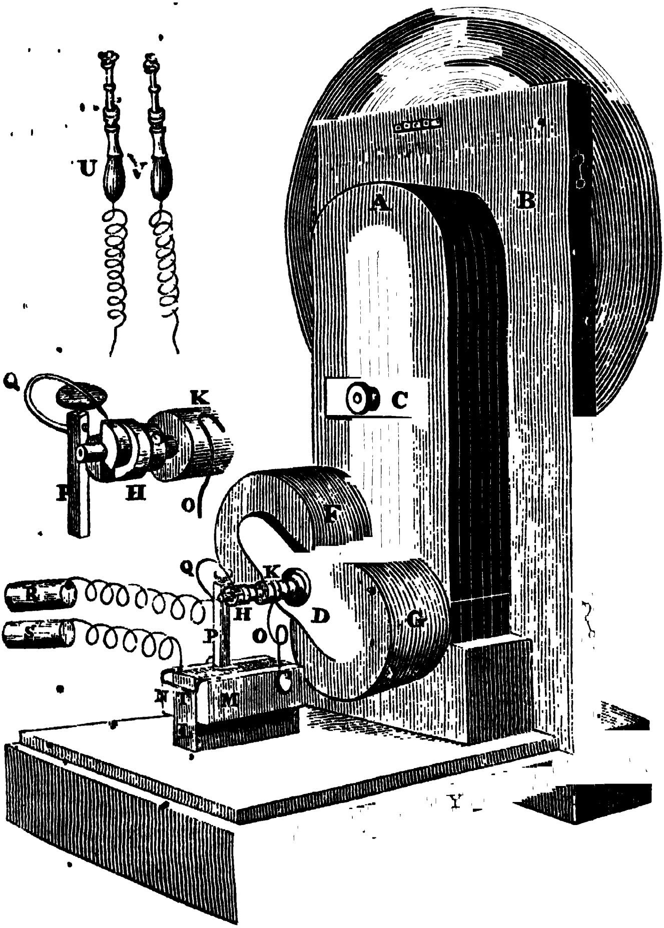
As soon as it was proved that electric currents could be disturbed, and set in motion by magnets, an attempt was made to construct an instrument by which the electricity could be concentrated. Mr. Saxton was the most successful. His instrument consists of powerful horse-shoe magnets placed in a horizontal position. Close to the poles of the magnet there is fixed an iron armature, so formed, that its two ends may be brought into contact with them. The armature is surrounded by two or more pieces of copper wire covered with silk for insulation, each half being bound by a separate wire. The ends of one wire, or sets of wires, are connected with a metallic disc, which may be made to dip into a cup containing mercury. The ends of the other wire are fastened to a slip of copper, so that when the armature is put into a rotatory motion by a suitable wheel the points may alternately dip into the mercury, the circumference of the disc being constantly immersed. It is in this way that the current induced by an alternate contact of the armature is con-

veyed away, the circuit being completed every time the point touches the mercury. This instrument has been with propriety called the magnetic machine.

The construction of perfect philosophical instruments must always be a work of time, for it is seldom, if ever, that the original inventor produces it in its best form, or with its most complete arrangements. We may therefore, without detracting from the merits of Mr. Saxton's arrangement, give the preference to the magnetic machine recently invented by Mr. Clarke of the Lowther Arcade. There are many reasons which induce us to prefer his arrangement, as best suited for the use of the experimenter, and especially the application of a method by which the use of mercury is avoided, and separate armatures may be applied, the one for effects resulting from quantity, and the other for intensity. By this instrument all the most important experiments in magnetic electricity may be performed. We shall now endeavour to describe the machine and its application in illustrating the electrical effects.

The figure at the commencement of this chapter is a representation of Mr. Clarke's magnetic machine, but it will be better described from fig. 95. A is a battery of six horseshoe magnets placed in a vertical position against a mahogany board B, supported by a stout bar C, through which a bolt is passed, firmly connecting it with the backboard. The *object of the inventor in this arrangement is, to secure an easy method of removing the magnets, and of adjusting the instrument, while at the same time it prevents those vibrations arising from the rotation of the wheel which*

Fig. 95.



would be liable to disarrange the apparatus. D is the armature, which screws into a brass mandril between the poles of the magnetic battery, and motion is given to it by the multiplying wheel E. Two armatures are provided, one called the intensity, and the other the quantity, armature. The former consists of two coils of fine insulated copper wire fifteen hundred yards long, coiled on cylinders, the commencement of each coil being soldered to the armature D. The quantity armature is attached, in the same manner, but the coils on each cylinder are only twenty yards long. K is a hollow brass cylinder attached to the armature D, and O is an iron wire spring pressing against the cylinder K at one end, and kept in metallic contact by a screw with the brass plate M, which is fixed to a wooden block L. P is a square brass pillar fitting into the brass plate N, which is similar to that represented to view, and marked by the letter M. This pillar may be raised to any height that may be required for experiment. H is the break-piece forming a part of the cylinder K; and Q is a metal spring that rubs upon it, a perfect metallic contact being maintained by the metallic screw at the end of the pillar P. T is a piece of copper wire connecting the brass plates M N. Now it will be perceived that D H Q P M are all in connexion with the commencement of each coil, and K O M with the termination.

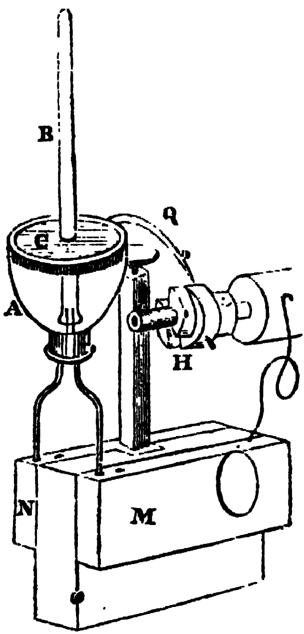
Such is the construction of the magnetic machine, and we may now proceed to describe, following as nearly as possible Mr. Clarke's account, the experiments which may be made with the separate armatures. The intensity armature is

chiefly used to exhibit chemical decompositions and to give shocks.

CHEMICAL EFFECTS.

The decomposition of water is a favourite and illustrative exhibition of the decomposing power of electricity. Water is, as already stated, in a former part of this work, a compound substance formed from the chemical union of the two gases, oxygen and hydrogen. In resolving this compound

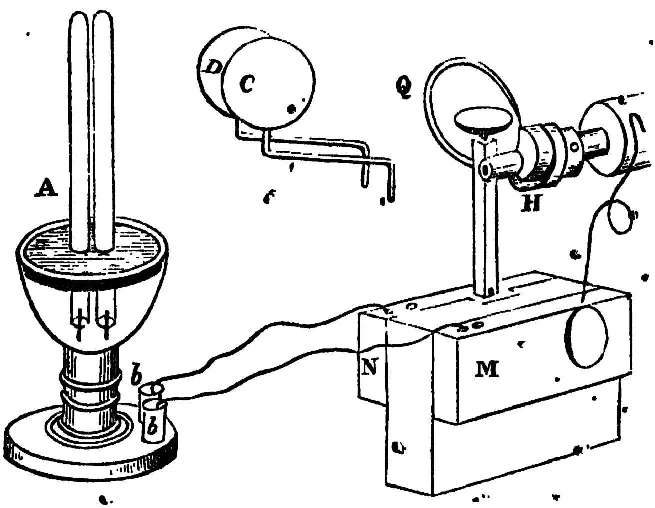
Fig. 96.



substance into its elementary aeriform constituents, the gases may be collected either in the same or separate vessels, by the use of suitable instruments;—both these methods may be exhibited.

Fig. 96, represents the instrument for collecting the gases in the same tube. A is a glass vessel, to which is fitted a piece of hard wood, through which thin platinum wires are fixed, entering the open end of the tube B, which is hermetically sealed at the top. C is a cork supporting the tube B, which is filled with acidulated water. When the instrument is put in motion and the wire Q is made to rub upon the cylindrical part of the break H, the magnetic electricity is given off and conducted by the vertical wires which are plunged into M and N. The decomposition is effected be-

Fig. 97.



tween the platinum points, causing a rapid ascension of the mixed gasses.

Fig. 97, is an arrangement for obtaining the gasses in separate tubes. A is a glass vessel with two tubes arranged in the manner already described, except that the platinum wires enter the separate apertures, and are connected with the two small cups *b b* which contain mercury, and are united with M and N by copper wires. C and D are plates of platina attached to copper wires by which they are united with M and N. If a piece of turmeric paper wetted with some neutral salt be placed between them, the decomposition may be easily exhibited by the change of colour which will result from the action of the electricity.

PHYSIOLOGICAL EFFECTS.

The physiological effects of the magnetic electricity upon the living body may be exhibited by adopting the arrangement in fig. 95. R and S are two brass conductors, one of which is connected with the plate N, and the other placed in the small hole at the end of the brass stem, which carries the break piece. When M and N are united by a copper wire T, and the person to be experimented on shall grasp the cylinders R and S, violent shocks will be suffered immediately the multiplying wheel is put into motion. Another way of performing this experiment is to place the conductors in two separate basins containing salt and water, and to immerse one hand in each basin; this method, says Mr. Clarke, is to be

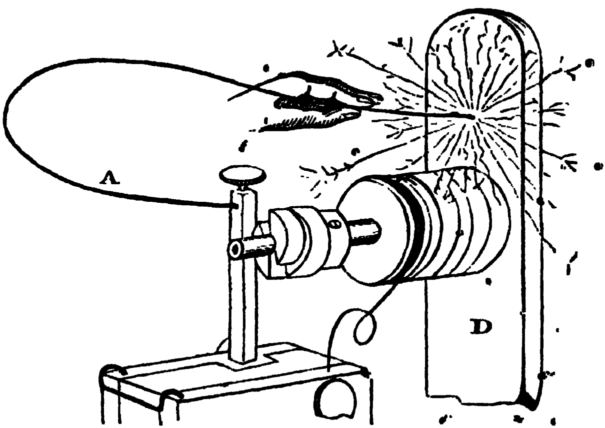
preferred, as it leaves the person who is electrified the power of quitting when he pleases. Not so with the conductors, for the muscles of the arm contract violently, so as to close the hands completely.

With the quantity armature we may obtain luminous, calorific, and magnetic effects, and also exhibit rotations similar to those obtained by Voltaic electricity.

LUMINOUS AND HEATING EFFECTS.

Fig. 98 represents the method of scintillating iron wire. A is a piece of wire firmly attached to the pillar P, fig. 95, and D the rotating armature. As soon as the instrument is put

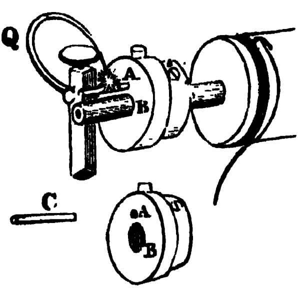
Fig. 98.



in motion, and the disengaged end of the wire is pressed upon the rotating armature, brilliant scintillations will be given off. This effect we are informed is entirely produced by soldering the wires of the coils to the armature, a process which at one time was supposed to destroy the effect of the instrument.

The arrangement represented in fig. 99, shews a method by which the various metals may be deflagrated so as to produce the various colours which distinguish them. The break is, in this instance, removed, and a brass piece B substituted. A wire of any metal C is connected with the pillar in the manner already explained, and the extremity of the spring Q is formed of the same metal. When the machine is put into motion, bright sparks will be produced, varying in colour according to the metal that is used.

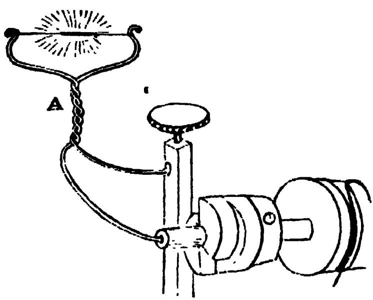
Fig. 99.



As the magnetic machine is able to scintillate iron wire, it may be readily supposed that it is capable of heating thin pla-

tina wire, and raising it in the same manner as a pair of Wollaston plates to a red heat. The arrangement used for this purpose is represented in fig. 100. Two pieces of copper wire are twisted together near the middle of their length. Be-

Fig. 100.

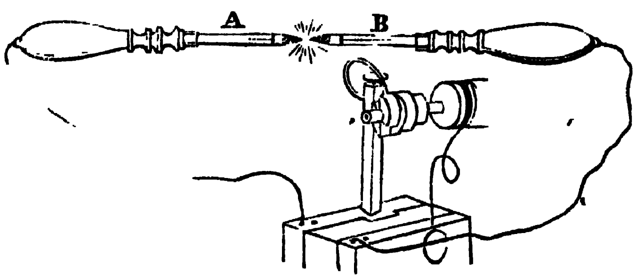


tween the ends above the union, the platina wire is placed, and the opposite end of one wire is connected with the pillar as before described, and that of the other is placed in the small hole at the end of the cylinder. Almost as soon as the electricity is generated, the platina gives evidence by its luminosity of the effect of the magnetic electricity. When the wire is red hot, gunpowder, ether, or any other inflammable substance may be ignited by it.

The ignition of charcoal points, which is so beautiful an experiment in Voltaic electricity, may be readily performed with the intensity armature of the magnetic machine. A and B are two directors similar to those used in common electricity, except that the wires proceeding from the plate N M,

fig. 97, pass through glass handles. Charcoal points are attached to the ends of the wire, and when brought near to each other, the machine being in action, a brilliant star of light is produced.

Fig. 101.



THERMAL ELECTRICITY.

It was long after the discovery, and even the investigation of Voltaic electricity, that Professor Seebeck noticed the existence of electric currents arising from an unequal temperature in metals. He found that when a brass wire was coiled round the ends of a bar of antimony, and heat was applied at one extremity, magnetic action was developed. It was at first supposed that this effect was due to some peculiarity in the metal itself, but a few experiments proved that it belonged to the metals as a class, altogether independent of their nature, contact, juncture, and even of the coil or helix that was formed. The only condition required was a perfect series of conductors.

"Reasoning from the analogy of the galvanic circuit," says Professor Cummings in his Report on the Science, read before the British Association, "it might have been imagined that as three elements were necessary in the one, so two metallic elements with heat acting the part of the third, might be required in the other; but it appeared from the earliest experiments, that a metallic bar, heated in contact with the same metal, gave considerable deviations to the galvanometer needle, and therefore that one metal alone sufficed for the development of thermo-electricity."

From the experiments of Yelin and other philosophers on the thermal electricity of a single metal, it is quite evident that any metallic substance unequally heated becomes the medium of transmission to electric currents excited within it. The magnetic effects which are produced, are only evidences of their presence; and judging from the effect upon the magnetic needle, it appears that the metals may be arranged in the following order—bismuth, antimony, zinc, silver, platina, copper, brass, gold, tin, and lead.

In the year 1831, Mr. Sturgeon published an extensive and curious series of experiments on the thermo-electric properties of single metals, by which it was proved that the direction of the electricity to or from the heated point depends upon some peculiarity of constitution, which the investigator sought for in vain. This experimentalist also discovered that in the same metal the course of the current depended greatly upon the figure it assumed. Whenever then a metal is unequally heated, its electrical condition is

disturbed, currents are generated, and the ordinary effects may be obtained.

Dr. Trail was the first who discovered that two metals symmetrically united throughout, would form a thermo-electric combination. In 1827 Mr. Christie published in the Philosophical Transactions a very interesting paper suggesting, and in some degree proving, that the diurnal variation of the compass needle, which seems to be chiefly dependent on the position of the sun, has in all probability a thermo-electric origin. As far as he could imitate natural phenomena by experiment, it appeared that the earth and its atmosphere form a thermo-electric combination put in motion by the sun. "Imitating this arrangement by a circular ring of copper surrounding a plate of bismuth, and applying heat to a point in the ring, he found that the characters and extents of the deviations were such, as would arise from the polarization of the plates in lines, nearly at right angles to the axis of the heat, contrary poles being opposite to each other in the two surfaces: and applying this to represent the state of the equatorial regions of the earth, we should have two magnetic poles in the northern, and two poles similarly posited on the southern side; the poles of different names being opposed to each other on the contrary sides of the equator." And it was also found that "when heat was applied to a point in the equator, of a copper shell, surrounding a sphere of bismuth, the deviation of the end of the needle of the same name as the latitude, was always towards the west when the place of heat was above the horizon, and towards the east when on the meridian below."

One of the most characteristic distinctions of electricity is, its almost instantaneous transmission through solid conductors of great length. Mr. Prideaux, in his examination of the question,—Is there any, and what difference between thermo-electricity, and that derived from other sources? takes this fact as one means of closely testing the identity of the currents produced in metals by heat with the electric agent. Fifty feet of iron wire (one of the worst metallic conductors) were cut into two lengths, and connected with a magnetest. "A thermo-electric pair of antimony and bismuth had their feet dipped, first into the mercury boxes of the magnetest, which produced a deflexion of 80°, and were then removed into the other boxes at the end of the wires, by which the deviation was reduced to 15°; the interposition of the iron wire between the excited metals and the magnetest withholding four-fifths of the deviation: yet was the instantaneous movement of the needles as evident in one case as in the other. So far then as promptitude of transmission through long wires is a distinction, thermo-electricity does not differ from the other kinds."

All the effects produced by ordinary and Voltaic electricity have now been obtained with the thermo-electric currents, though philosophers were long foiled by the small intensity of the fluid; and this, as supposed by many electricians, is almost the only difference between the Voltaic and thermal electricities.

The theory we have adopted to explain the production of electricity by other causes is equally, or if possible more, applicable to that of which we are now speaking. The whole

material world is in a great degree under the influence of electricity. All substances contain a certain amount, if we may so speak, of the electric agent, and none of the alterations they suffer in constitution or in form can separate it from them, although its quantity, intensity, and effects may be changed. If we rub a substance, its electrical condition is disturbed, and the agent itself is set free; if we bring it in contact with some other substance or cause it to exert a chemical action, the same agent is produced, but by what means the want of equilibrium is provided for, we are at present quite unable to state.

When the attention of scientific men was entirely devoted to the investigation of that electricity produced by friction, there was a long discussion upon the nature of the agent; some maintaining that it was a single fluid capable of existing in different states which they called plus and minus, and others imagining that there were two fluids having opposite and contrary qualities. The electricians of the present day, finding themselves surrounded by innumerable difficulties in every investigation, have forgotten their former feuds, and devote themselves with great energy to discover the effects, without violently defending their opinions as to the nature and constitution, of the agent. The science of heat has been studied for a long period of time, but we are now as unable to answer the apparently simple question, what is it? as were the earliest investigators. So it is probable we may pursue our enquiries for ages to come into the effects and operations of electricity without knowing anything of its physical constitution. There is no substance in which it does not

exist, and none in which it may not be by some method developed, or in other words set free. Yet such is the subtlety of the agent, that although we may disturb its condition, it is perfectly impossible to remove it entirely from any body, whether it be in the form of a solid, liquid, or vapour. The changes to which bodies are subject, whether they be physical or chemical, may, perhaps, in every instance be traced to an alteration in their electrical state, but we feel assured that matter and electricity, whatever the agent may be, can never be separated.

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